CAPSULE

ELECTRONICS ENGINEERING

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Youth Competition Times

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ELECTRONICS ENGINEERING

Capsule

Useful for All ELECTRONICS ENGINEERING Competitive Exams...

Youth Competition Times

ELECTRONICS ENGINEERING CAPSULE

Useful for All Competitive Exams :

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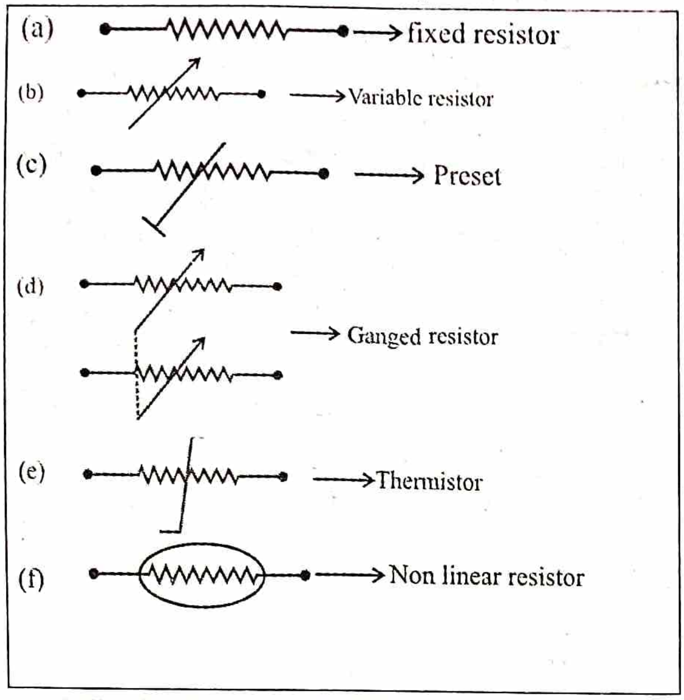
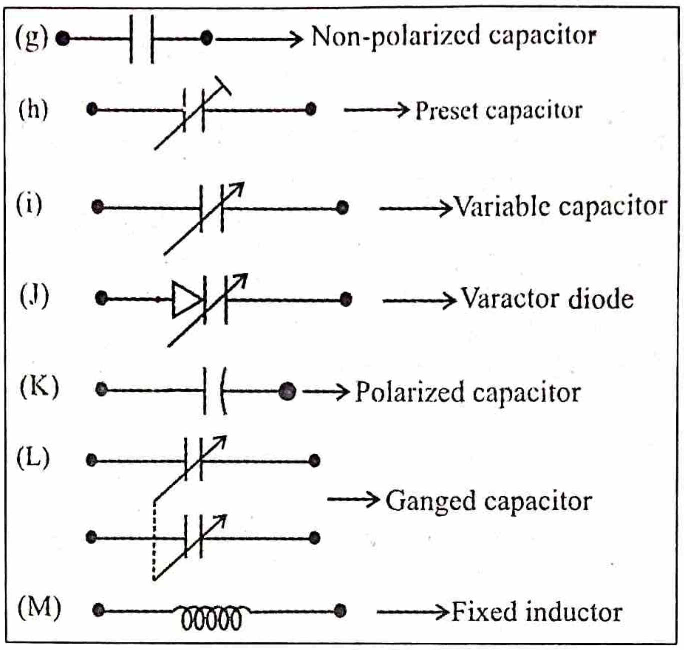
BASIC ELECTRONICS ENGINEERING

■ Electronics components symbol-


(a) →fixed resistor
(b) →Variable resistor
(c) → Preset
(d) → Ganged resistor
(e) →Thermistor
(f) →Non linear resistor


(g) → Non-polarized capacitor
(h) →Preset capacitor
(i) →Variable capacitor
(J) →Varactor diode
(K) →Polarized capacitor
(L) →Ganged capacitor
(M) →Fixed inductor

• Comparison of different types of resisters-

Type of resistor	Resistive material	Range	Power rating	Tolerance	Cost	Noise	High frequency response	Temp. Coefficient
Carbon Composition	Carbon- Clay	upto 20MΩ	upto 2W	+5% to ± 20%	Moderate	Low	Better	Low
Carbon and metal film	carbon or thin layer of metal	upto20 MΩ	More than carbon composition	± 1% to ± 5%	Cheap	High	Normal	More than carbon composition
Wire wound	wire wrapped around an insulating core	upto100 kΩ	upto 200 W	≃ ± 1%	Costly	Very Low	Poor	Medium

• Comparison of Different types of capacitors-

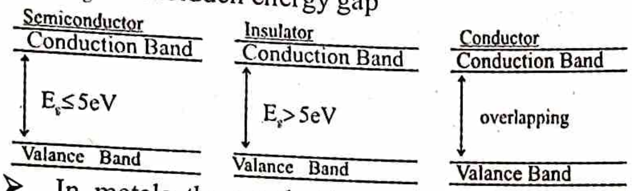
Type of Capacitor	Dielectric (Dielectric constant)	Range	Voltage Rating	Tolerance	Leakage current	Polarity	Application
Paper Capacitor	Impregnated paper (2-6)	0.0005 μF to 10 μF	100V to several thousand volts	± 10%	Low	No	AC, DC, High voltage and High Current
Polyester capacitor	Polyester (2.0)	0.0005μF to 10μF	upto 2000V	± 10%	Low	No	tuned circuit, Digital computer
Ceramic capacitor	Ceramic (80-1200)	3 pf to 2μF	3V to 6000V	± 10% to ± 20%	Low	No	Coupling capacitor, Bypass capacitor
Mica capacitor	Mica (3-8)	1 pf to 1 μF	500 V, 40kV at high frequency	± 0.5%	Low	No	Temperature varying
Electrolyte Capacitor	Aluminium Oxide (7)	1μF to several thousands μF	1V to 500V	± 10%	High	Yes	Filter circuit, coupling capacitor

- **Energy Bandgap** $\boxed{E_g = E_c - E_v}$

E_c = Energy level of conduction band

E_v = Energy level of valance band

E_g = Forbidden energy gap


Semiconductor
Conduction Band
E_g≤5eV
Valance Band
Insulator
Conduction Band
E_g>5eV
Valance Band
Conductor
Conduction Band
overlapping
Valance Band

➢ In metals the conduction bands and valance band overlap with each other.

➢ In insulator energy band gap is very high.

➢ In semiconductor energy band gap is relatively small.

➢ Valance band can never be empty.

➢ $1 \text{eV} = 1.6 \times 10^{-19}$ Joule

- **Fermi Level**

➢ It indicates carrier concentration.

➢ Fermi level also gives the information that, at 0^0K above fermi level, all are empty and below fermi level all allowed energy levels are filled.

$$\boxed{f(E) = \frac{1}{1+e^{[(E-E_F)/KT]}}} \quad \boxed{K = 1.38 \times 10^{-23} \text{J/K}}$$

Where, E: given energy level
E_F: fermi-level
K: Boltzmann's constant
T: Absolute temperature

Note:

f(E) doesn't gives:
(i) Number of electrons in a given energy level
(ii) Number of energy levels with electrons.

At T = 0K

case (i) : $E << E_F$:

$$f(E) = \frac{1}{1+e^{(E-E_f)/KT}} = \frac{1}{1+e^{-\infty}} = 1 \Rightarrow 100\%$$

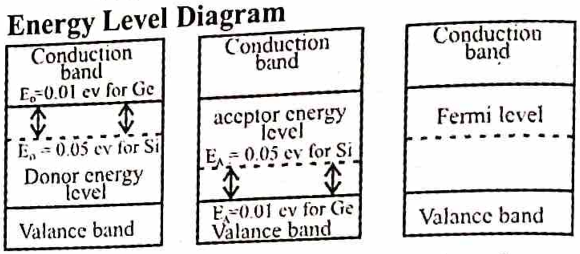
case (ii) : $E = E_F$: at $T \neq 0$

$$f(E) = \frac{1}{1+1} = \frac{1}{2} = 0.5 \Rightarrow 50\%$$

case (iii) : $E >> E_F$: at T = 0K

$$f(E) = \frac{1}{1+e^{(E-E_f)/KT}} = \frac{1}{1+e^{+\infty}} = 0 \Rightarrow 0\%$$

- **Energy Level Diagram**


Conduction band
E_D=0.01 ev for Ge
E_D = 0.05 ev for Si
Donor energy level
Valance band
Conduction band
acceptor energy level
E_A = 0.05 ev for Si
E_A=0.01 ev for Ge
Valance band
Conduction band
Fermi level
Valance band

➢ The Fermi Level in intrinsic semiconductor lies center of the forbidden gap.

➢ The Fermi Level in P-type semiconductor lies above the valance band

➢ The Fermi Level in N-type semiconductor lies below the conduction band.

- **Effect of temperature on Fermi-level:** When temperature goes on increases extrinsic semiconductor gradually gets the intrinsic behaviour when thermally generated e^- concentration dominates the donor electrons, so that Fermi-level to the mid-gap.
- **Fermi energy level:** The Energy of the electron at 0K is called Fermi energy (Unit → eV)

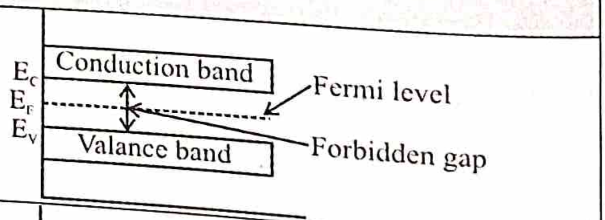
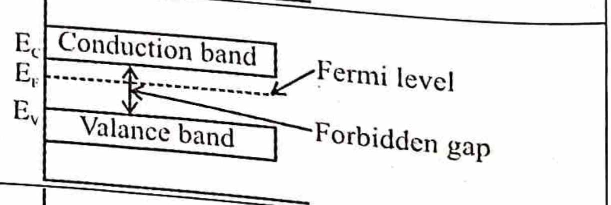
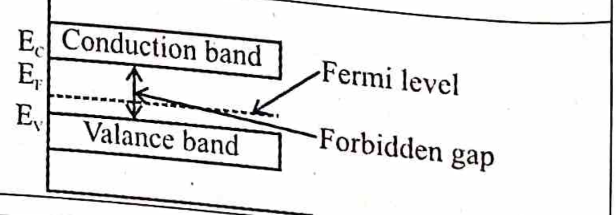
$$\boxed{\text{Fermi Energy} = \text{Maximum kinetic energy of electron}}$$

$$\boxed{E_F = \frac{1}{2} mv^2} \qquad \boxed{V = \sqrt{\frac{2E_F}{m}}}$$

➢ If the Fermi function is f(E) of any electron, then the Fermi function for the hole = 1–f(E)

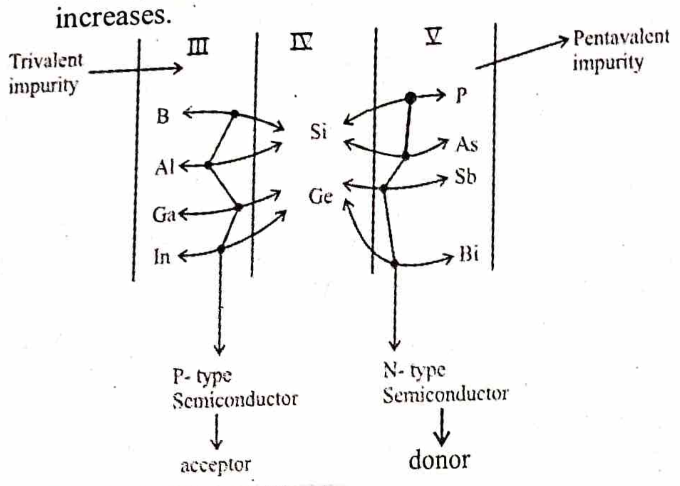
➢ $E_g = KT \ell n \left(\frac{N_C . N_V}{n_i^2} \right)$

- **Fermi level in Intrinsic SC-**
- **Fermi level in different type semiconductor**

Semiconductor	**Fermi formula**	**Fermi diagram**
Intrinsic semiconductor	$E_F = \frac{E_C + E_V}{2} - \frac{KT}{2} \ln \left(\frac{N_C}{N_V} \right)$	 E_C E_F E_V Conduction band Fermi level Valance band Forbidden gap
n-type semiconductor	$E_F = E_C - KT \ln \left(\frac{N_C}{N_D} \right)$	 E_C E_F E_V Conduction band Fermi level Valance band Forbidden gap
p-type semiconductor	$E_F = E_V + KT \ln \left(\frac{N_V}{N_A} \right)$	 E_C E_F E_V Conduction band Fermi level Valance band Forbidden gap

- **Doping -** The process of adding of impurity into pure semiconductor.

➢ Doping increases then carrier concentration increases.



- **Standard Doping Level**

➢ $\boxed{\text{Moderate doping}} \Rightarrow 1:[10^6 \text{ to } 10^8] \rightarrow$ N and P type SC

➢ $\boxed{\text{Lightly doping}} \Rightarrow 1:10^{11} \rightarrow N^-$ and P^- type SC

➢ $\boxed{\text{Highly doping}} \Rightarrow 1:10^3 \rightarrow N^+$ and P^+ type SC

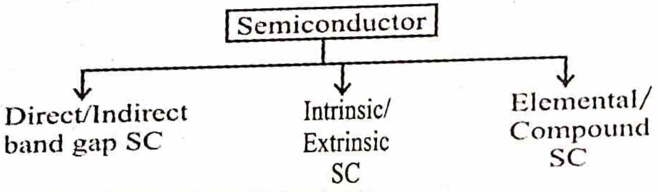
➢ Intrinsic SC $\xrightarrow{1:10^8}$ Extrinsic SC

➢ $1:10^6$ or 1 in 10^6 or $1/10^6$ is read as , 1 impurity atom in 10^6 atoms.

➢ Conductor ⟶ Metallic Bond

➢ Semiconductor ⟶ Covalent Bond

➢ Insulator ⟶ Ionic Bond



- **Elemental semiconductor**

  ➢only single element ➢ C, Si, Ge, Pb

- **Compound semiconductor**

  ➢ at least two elements ➢ GaAs, GaN

- **Direct/Indirect Band gap Semiconductor:**

➢ Light is produced in the direct band gap.

➢ Heat is produced in the indirect band gap.

➢ Direct Band gap SC- GaAs, GaN, GaSb, CdS, InGaAs, ZnS

➢ Indirect Band gap SC- Si, Ge, AlAs, AlSb, PbSe, GaP.

- **Intrinsic SC -** Extremely pure semiconductor.
- **Extrinsic SC** – Doped with specific impurities.
- **Effect of Doping on conductivity (For Ge)**

➢ $1 : 10^8 \rightarrow$ 12 times ➢ $10 : 10^7 \rightarrow$ 120 times

➢ $1 : 10^6 \rightarrow$ 1200 times

☞ **Remember point**

> ➢ A semiconductor at absolute zero temperature, behaves as a perfect insulator.

> ➢ In a intrinsic semiconductor the resistivity (inverse of conductivity) decreases as the temperature increases. Hence the semiconductor have negative temperature coefficient of resistance.

- **Electrical Neutrality**

➢ n- type and p- type are electrical Neutral.

$$\boxed{N_D + p = N_A + n}$$

Where. $N_D \rightarrow$ Donor, $N_A \rightarrow$ Acceptor

p → Positive charge, n → Negative charge.

- **Energy Band gap. (E_g)-** $\boxed{E_g \propto \frac{1}{\text{temp.}}}$

	Ge	Si	GaAs
E_{g0K}	0.785 eV	1.21 eV	1.52 eV
E_{g300K}	0.72eV	1.1 eV	1.42 eV

- **Mass Action Law-:** $\boxed{n \cdot p = n_i^2}$

Where, n = concentration of electron

p = Concentration of hole.

n_i = Intrinsic carrier concentration.

➢ Mass action law mostly used for extrinsic semiconductor to find minority carrier concentration.

➢ When temperature changes, n_i^2 also changes. So mass-action law not valid when temperature changes.

$$\boxed{\text{Minority carrier conc.} = \frac{n_i^2}{\text{majority carrier conc.}}}$$

➢ Minority carriers depend on → Temperature

➢ Majority carriers depend on → Doping

$$\boxed{\text{Minority carrier conc.} = \frac{n_i^2}{\text{Doping conc.}}}$$

- **Thermal Voltage -** $\boxed{V_T = \frac{KT}{q}}$ $\boxed{V_T = \frac{T}{11600}}$

$$\boxed{V_T = 26\text{mV}}$$

- **Boltzman constant -**

$\boxed{\bar{K} = 1.38 \times 10^{-23} \text{ J/}^\circ\text{K}}$ $\boxed{K = 8.62 \times 10^{-5} \text{ eV/}^\circ\text{K}}$

- **Diffusion coefficient -**

Element	**Formula**	**Ge (300K)**	**Si (300K)**
Electron(e^-)	$D_n = \mu_n \times V_T$	99 cm^2/sec	34 cm^2/sec
Hole (H^+)	$D_p = \mu_p \times V_T$	47 cm^2/sec	13 cm^2/sec

$\boxed{\frac{D_n}{\mu_n} = \frac{D_p}{\mu_p} = \frac{KT}{q} = V_T}$ (Einstein relation)

Where,

D_n = diffusion coefficient of electron

D_p = diffusion coefficient of hole

μ_n = mobility of electron

μ_p = mobility of hole

V_T = thermal voltage

T = temperature

K = Boltzman constant

- ➢ Diffusion coefficient decreases with temperature.

- **Diffusion process**

- ➢ Diffusion is the Natural process of the random motion of the individual molecules.
- ➢ Diffusion happens due to concentration gradient.
- ➢ Diffusion current density

$$\boxed{J_n(\text{diff}) = +q\,D_n\frac{dn(x)}{dx}}\;:\;\boxed{J_p(\text{diff}) = -q\,D_p\frac{dp(x)}{dx}}$$

Where,

J_n(diff) = diffusion current density of electron

J_p (diff) = diffusion current density of holes.

D_n = electron diffusion coefficient.

D_p = Hole diffusion coefficient.

n(x)= Profile of electron with respect to x.

p(x) = Profile of holes with respect to x.

- ➢ Diffusion currents flow only in semiconductors.
- ➢ In a semiconductor diffusion is maintained due to unequal distribution of charge carriers.

- **Diffusion Length**

Electrons (e^-)	**Holes (H^+)**
$L_n = \sqrt{D_n\tau_n} = \sqrt{\mu_n V_T \tau_n}$	$L_p = \sqrt{D_p\tau_p} = \sqrt{\mu_p V_T \tau_p}$
Where, D_n= Diffusion coefficient of electron τ_n= Carrier life time of electron D_p= Diffusion coefficient of holes τ_p= Carrier life time of holes μ = mobility V_T = thermal voltage	

- **Drift process-** Transport of carrier under the influence of applied electric field.

$$\boxed{J_n(\text{drift}) = nq\mu_n E}\;\boxed{J_p(\text{drift}) = nq\mu_p E}$$

Where, J_n(drift) = Drift current density due to electrons

J_p (drift) = Drift current density due to holes.

n, p = Concentration of electron and holes respectively

E = Applied electric field

- **Total current Density**

$$\boxed{J_n(x) = q\mu_n n(x)E(x) + qD_n\frac{dn(x)}{dx}}\quad\boxed{J(x) = J_n(x) + J_p(x)}$$

$$\boxed{J_p(x) = q\mu_p p(x)E(x) - qD_p\frac{dp(x)}{dx}}$$ J(x) = overall current density

- **Conductivity-**

Element	**Conductivity formula**
Metal	$\sigma = q\mu n = \rho\mu = \frac{J}{E}$
Intrinsic semiconductor	$\boxed{\sigma = n_i q\mu}$
Extrinsic Semiconductor	$\boxed{n-\text{type} \rightarrow \sigma = nq\mu_n}$ $\boxed{p-\text{type} \rightarrow \sigma = pq\mu_p}$
Intrinsic Semiconductor	$\boxed{\sigma = n_i q(\mu_n + \mu_p)}$

For minimum conductivity

for P-type:

$$P' = n_i\sqrt{\left(\frac{\mu_n}{\mu_p}\right)}$$

for n-type:

$$n = n_i\sqrt{\left(\frac{\mu_p}{\mu_n}\right)}$$

For minimum conductivity condition for p-type semiconductor is $\sigma_{min} = 2n_i\sqrt{\mu_n\mu_p}.q$

Where, σ = Conductivity, n_i = Carrier Concentration

μ_n = Mobility of electrons, μ_p = Mobility of Holes

q = Charge

- ➢ In metal when temperature increases mobility of charge carrier decreases therefore conductivity decreases with temperature.
- ➢ In metal free electron concentration is independent of temperature.
- ➢ In semiconductor conductivity mainly depends on carrier concentration.
- ➢ For 1°C Ge → σ ↑ by 6% : Si σ↑ by 8%.

- **Electric field intensity -**

$$\boxed{E = \frac{|dV|}{dt}}\,V/m$$

Where,

dV = Change in voltage

dt = thickness of bar

- ➢ Anywhere of the semiconductor bar field intensity is same.

- **Mobility of charge Carriers**

- ➢ It is drift velocity per unit electric field.
- ➢ $\boxed{\text{unit} \rightarrow \frac{m^2}{V-s}}$ **or** $\frac{cm^2}{V-s}$
- ➢ It defined how fast the charge carrier travels from one place to another and is given by - $\boxed{\mu = \frac{V_d}{E}}$

Where, V_d = drift velocity , E = Electric field

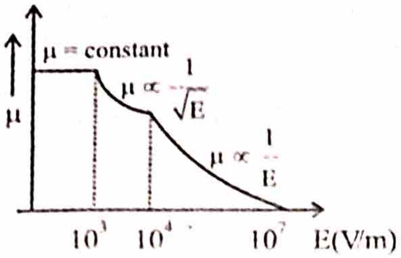
Mobility	**Ge**	**Si**	**GaAs**
e^- mobility (μ_n)	3800 cm^2/Vsec	1300 cm^2/Vsec	4600 cm^2/Vsec
hole mobility (μ_p)	1800 cm^2/Vsec	500 cm^2/Vsec	400 cm^2/Vsec

- ➢ Mobility of charge carriers decreases with increases temperature and varies as -: $\boxed{\mu \propto T^{-m}}$

Where, m is constant

$$\boxed{\begin{array}{l}\text{In Ge} \rightarrow m = 1.66 \text{ for } e^- \text{ and } 2.33 \text{ for hole}\\ \text{In Si} \rightarrow m = 2.5 \text{ for } e^- \text{ and } 2.7 \text{ for hole}\end{array}}$$

- ➢ Mobility also varies with applied electric field



μ = constant	$E < 10^3\ V/cm$
$\mu \propto \frac{1}{\sqrt{E}}$	$10^3 < E < 10^4\ V/cm$
$\mu \propto \frac{1}{E}$	$E < 10^4\ V/cm$

- ➢ At smaller electric field mobility is constant
- ➢ At very high electric field product of mobility and electric field becomes constant and is equal to saturation value of drift velocity.
- ➢ Overall mobility-

$$\boxed{\frac{1}{\mu_T} = \frac{1}{\mu_1} + \frac{1}{\mu_2} + \frac{1}{\mu_3} + \ldots\ldots\ldots\ldots\ldots}$$

Where, μ_T = overall mobility

$\mu_1, \mu_2, \mu_3 \rightarrow$ mobility corresponding to different scattering Mechanism.

- **Wave length of light (λ)** - $\boxed{\lambda = \frac{1.24}{E_g(eV)}}$ μm

E_g = Energy gap of the material in Electron Volt

$\boxed{\text{For visible light } \lambda = 0.38\mu m \text{ to } 0.76\mu m}$

$\boxed{\text{For infrared } \lambda > 0.76\,\mu m}$

- **Important point related to Si**
- ➢ Si has better thermal stability.
- ➢ It is more suitable for used in switching application.
- ➢ High power handling capacity.
- ➢ Uses in high power device Ex. SCR. DIAC, TRIAC
- ➢ Low frequency application, ➢ Low leakage current (nA)
- ➢ Atomic Number → 14, ➢ atomic weight → 28.086
- **Important point related to Ge**
- ➢ It is higher conductivity due to large mobility.
- ➢ Relatively more suitable for high frequency applications.
- ➢ Higher leakage current (μA), ➢ atomic Number →32
- ➢ atomic weight → 72.63
- ➢ Large conductivity than, Ge > Si
- **Important point related to GaAs**
- ➢ It is a direct band gap Semiconductor.
- ➢ Covalent bond present, ➢Switching time very small.
- ➢ Used in microwave device.
- **Used-** LED, LASER, Tunnel diode, varactor diode, PIN diode

- **Intrinsic Concentration (n_i)**

$\boxed{n = p = n_i}$ $\boxed{n_i = \sqrt{A_0}\,T^{3/2} e^{\frac{-Eg}{2KT}}}$

$\boxed{\begin{matrix} n_i^2 \propto T^3 \\ n_i \propto T^{3/2} \end{matrix}}$ A_0 = material constant

Hence n_i varies non-linear with temp., At T= 300K

$\boxed{Si\text{-}n_i = 1.5 \times 10^{10}\ atom/cm^3}$ $\boxed{Ge\text{-}n_i = 2.5 \times 10^{13}\ atom/cm^3}$

- **Hall voltage and Hall coefficient**

Hall voltage	Hall coefficient
$\boxed{V_H = E_H d = \frac{BI}{\rho W} = R_H \frac{BI}{W}}$	$\boxed{R_H = \frac{1}{\rho} = \frac{1}{n.q} = \frac{1}{pq}}$
Where, E = Electric field d = Distance between upper and Lower surface of specimen W = Width of specimen. B = Applied magnetic field I = Current flowing in specimen ρ = Charge density	Where, p = Hole concentration n = electron concentration e or q = charge of electron
Metal → (–ve) n-type SC → (–ve) p-type SC → (+ve) Intrinsic SC → (0)	Metal → (–ve) n-type SC → (–ve) p-type SC → (+ve) Intrinsic SC → (zero)

- By using the Hall effect the conductivity of the semiconductor can be determined

$$\boxed{\sigma = \frac{1}{R_H}\mu}$$

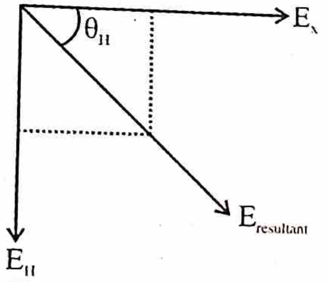
- By considering the random thermal motion we get mobility

$$\boxed{\mu = \left(\frac{8}{3\pi}\right)\sigma R_H}$$

☞ Remember point

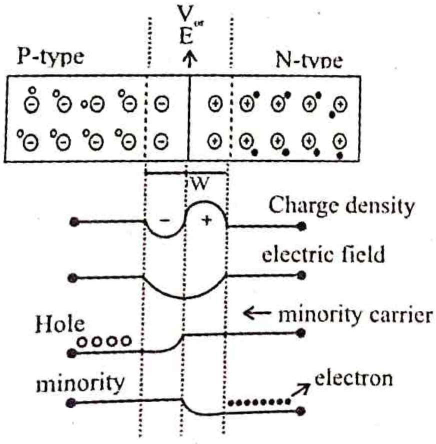
- ➢ Hall effect is utilized in determining whether a given material is metal, n-type SC, p-type SC.
- ➢ For Metal, value of V_H is lesser compared to SC.
- ➢ Hall voltage negative for metal or n-type SC.
- ➢ Hall voltage is positive for p- type SC.
- ➢ Hall voltage zero for intrinsic SC.
- ➢ Hall voltage is strong in semiconductor and weak in metal
- ➢ It can used in finding mobility of charge carrier, concentration of charge carriers and type of SC.
- ➢ It is utilized in Hall effect multiplier.
- ➢ In metal Hall coefficient (R_H) increase with temperature
- ➢ In pure Semiconductor, (R_H) decreased with temperature.
- ➢ In extrinsic SC, R_H is independent of temperature.
- ➢ Hall Voltage range → μV→Metals, to mV→ SC
- ➢ Mobility of majority carrier Calculate ⇒ Hall effect

- Mobility of minority carrier and diffusion constant Calculate ⇒ Haynes-schokely experiment.
- The specimen must be square or rectangular in shape.
- Conductivity of extrinsic SC at 0K is Zero.
- Conductivity of extrinsic SC initially increases when temperature rises above 0K.
- Conductivity of extrinsic SC decreases with increases in temperature above normal temperature.
- At curie temperature, conductivity becomes equal to intrinsic conductivity.
- Conductivity increases with increase in doping Concentration.
- Magneto field meter is an instrument operating on the principle of Hall-effect (used for magnetic flux density measurement).
- Hall voltage used to measure the signal power in the EM wave.
- Hall-effect is used to design transducer.
- Hall-effect used to measure the magnetic flux density.
- In extrinsic semiconductor, Hall co-efficient is independent of temperature.
- In intrinsic semiconductor, Hall co-efficient decreases with the temperature.
- Hall effect is used to measurement of displacement.
- Hall Angle :



$$\boxed{\theta_H = \tan^{-1}(\mu.B)}$$

- **PN Junction diode**



Width of Depletion layer- $\boxed{W = \sqrt{\frac{2\varepsilon V_0}{q}\left(\frac{N_A + N_D}{N_A \cdot N_D}\right)}}$

Where, N_A= Accepter concentration,
N_D = Donor concentration,
$\varepsilon = \varepsilon_0\ \varepsilon_r$

$\varepsilon_r = 12$ for Si, $\varepsilon_r = 16$ for Ge
ε_r = relative permittivity, ε_0 = Permittivity in free space.

- **Depletion layer**
- It is formed due to the diffusion of majority carrier.
- Immobile ions and covalent bonds are present in it.
- The depletion layer has negative ions on the p side and positive ions on the n side.
- Normally its thickness is 0.5 μm.
- The depletion layer blocks the majority and passes it to the minority $\boxed{W = \frac{1}{\sqrt{\text{Doping}}}}$
- Depletion layer also known as transition layer or space charge width.
- Number of free electron in depletion layer is zero.
- If we reverse bias the diode by voltage V then in formula of depletion width V_0 is replaced by $|V_0 + V|$.
- Depletion width increases with reverse bias and decrease with forward biased.
- Cut-in voltage also known as offset voltage, threshold voltage, knee voltage, break voltage.
- **Width of depletion Layer Depends on**
- Doping concentration , ➢ Contact potential
- The type of material used for fabrication (ε)
- **Expression for width of depletion layer:**
- $x_{n_0} = \frac{W.N_A}{N_A + N_D}$, $x_{p_0} = \frac{W.N_D}{N_A + N_D}$
- $W_p N_A = W_n N_D$
- **Maximum Electric field in p-n junction:**
- The maximum electric field occurs at the junction between the p–type and n-type material
- $|E_{max}| = \frac{e.N_D.x_n}{\epsilon_s}$ or $|E_{max}| = \frac{2V_{bi}}{W}$
- **Contact potential** - $V_0 = V_T \ln\left[\frac{N_A N_D}{n_i^2}\right]$ $\boxed{V_T = \frac{KT}{q}}$

  $V_0 \Rightarrow$ Contact potential
- Contact potential also known as potential barrier, Built-in potential, diffusion potential.
- **Depletion width cannot measure with a voltmeter-**
- Due to the formation of the depletion Layer
- due to diffusion (majority)
- due to drift (minority)
- due to potential Barrier.
- **Current Equation** - $I_f = I_o\left[e^{V_d/\eta V_T} - 1\right]$

  Where, I_o = Reverse saturation or Leakage current
  V_d = Voltage across diode.
  η = Recombination factor
  V_T = Thermal voltage
- **Leakage Current**
- Also known as minority carrier current, thermally generated current, reverse saturation current

$$\boxed{I_o(T_2) = I_o(T_1) \times 2^{\frac{T_2 - T_1}{10}}}$$

Where, $I_o(T_2)$ = Reverse saturation current at temperature T_2

$I_o(T_1)$ = Reverse Saturation current at temperature T_1

Here $\boxed{T_2 > T_1}$

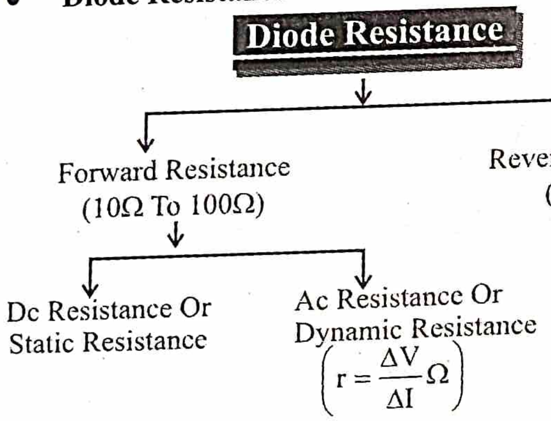
- Does not depend on applied voltage.
- It's only depends on temperature.
- For better performance I_o should be small or negligible.
- Ge → μA, Si → nA
- Temperature withstand capacity
  Ge → 100°C, Si → 200°C
- Maximum reverse biased voltage at which the diode can withstand
  Ge → 400Voltage, Si → 1000Voltage
- $I_o \rightarrow$ 1°C increase → 7% ↑ in I_o
- $I_o \rightarrow$ 10 °C increase → 2 I_o or double.

Semiconductor	Cut-in voltage	operating temp.
Ge	0.3V	75 °C to +100°C
Si	0.7V	175°C to +200°C

- for 1 °C rise in temperature cut-in voltage decreases by 2.5 mV

$$\boxed{\frac{dv}{dt} = -2.5\,\text{mV}/{}^\circ\text{C}}$$

- **Diode Resistance-**


Diode Resistance
Forward Resistance
(10Ω To 100Ω)
Reverse Resistance
(r_r>1MΩ)
Dc Resistance Or
Static Resistance
Ac Resistance Or
Dynamic Resistance
$\left(r = \frac{\Delta V}{\Delta I}\Omega\right)$

- **DC Resistance** $\boxed{R_f = \frac{V}{I}}$

It is the Resistance of Diode when signal is not applied.

- **AC Resistance** $\boxed{r = \frac{\eta V_T}{I_f}}$ for $\eta \rightarrow 1$ for Ge, 2 for Si

Where, η = Recombination factor

I_f = forward current V_T = Thermal voltage

Static Resistance is always greater than AC Resistance.

- **Junction Capacitance** $\boxed{C_j = \frac{A\varepsilon}{W}}$

Where, A - Area of cross-section of diode
W - Width of depletion region
ε - Permittivity of material

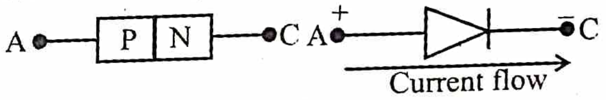
- Depletion layer in a p-n junction behave as a parallel plate capacitance and capacitance is given by

$$\boxed{C_j = \left|\frac{dQ}{d(V_0 - V)}\right| = \frac{A}{2}\left[\frac{2q\varepsilon}{(V_0 - V)}\frac{N_A N_D}{N_A + N_D}\right]^{\frac{1}{2}}}$$

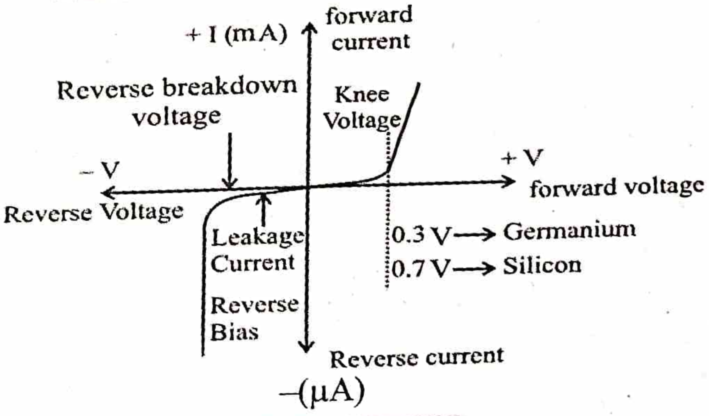
Where, V = Applied voltage, A = Area of cross- section

- In case of reverse bias transition capacitance C_T is same as junction capacitance.
- Transition Capacitance also known as Depletion capacitance.
- Transition capacitance $\boxed{C_T \propto V^{-n}}$
- Forward biased capacitance also known as Diffusion capacitance C_D or storage capacitance.
- Junction Capacitance $\boxed{C_j \propto \frac{1}{W}} \Rightarrow \boxed{C_j \propto \sqrt{\text{Doping}}}$
- Typical value of diffusion capacitance 0.02 μF
- Diffusion capacitance $\boxed{C_D = \frac{\tau I_F}{\eta V_T}}$ Farads.
- C_D always greater than C_T

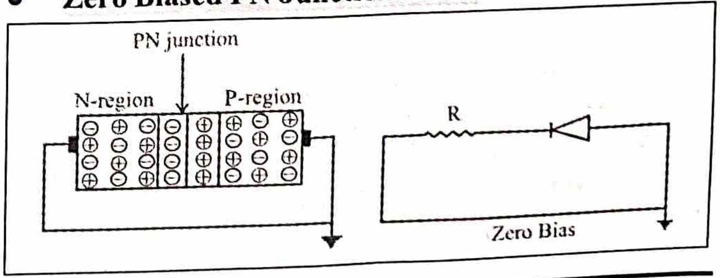
- **Notation and symbol of PN- Junction diode-**


A
P
N
C
A
+
−
C
Current flow

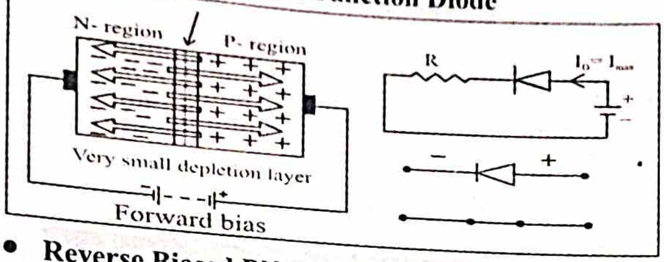
- **I-V Characteristics :**



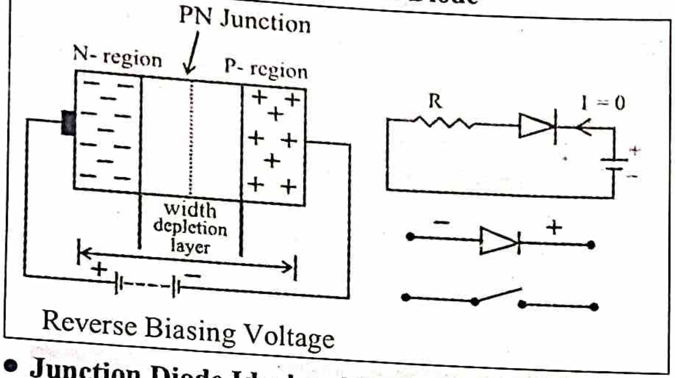
- **Zero Biased PN Junction Diode**


PN junction
N-region
P-region
R
Zero Bias

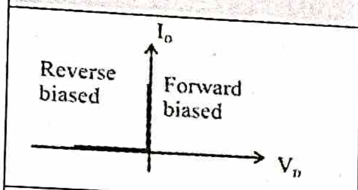
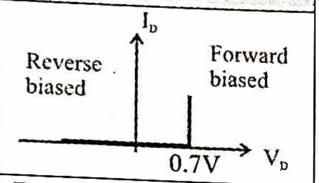
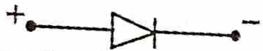
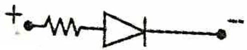
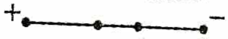
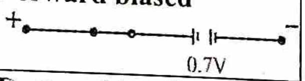
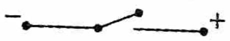
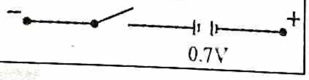
- **Forward Biased PN Junction Diode**



- **Reverse Biased PN Junction Diode**

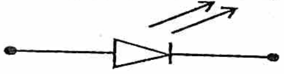


- **Junction Diode Ideal and Real Characteristics**

Ideal Diode	Real or practical Diode (Si)
	
Ideal diode 	**Real Diode** 
Forward biased 	**Forward biased** 
Reverse biased 	**Reverse biased** 

❑ Semiconductor Devices

• Light Emitting Diode (LED)



- This is an active device.
- It works on the principle of electro-luminescence.
- It will emit light when properly excited.
- Depletion layer is large as compared to Normal diode.
- It is fabricated using direct band gap material (GaAs).
- It emits light due to a large number of recombination at junction.
- Colour of light depends on concentration of dopant.
- It is always operated under forward biased.
- With a forward current of 20 mA, LED gives out the maximum intensity of light.
- In reverse bias it works like a normal diode.

- **Light colour depends on**
- On the wavelength and frequency of radiated light
- Type of concentration of dopant.

- **Typical LED characteristics-**

Semiconductor Material	Wavelength	Colour
GaAs	850-940 nm	Infra-Red
GaAsP	630-660 nm	Red
GaAsP:N	585-595 nm	Yellow
AlGaP	550-571 nm	Green
SiC	430-505 nm	Blue
GaInN	450 nm	White

- Power dissipation in LED-mW

- **LCD- (Liquid Crystal Display)**
- It is a passive device.
- Dynamic light scattering
- Power dissipation is in μW
- Response time is in msec.
- Operating life is 50,000+ hrs
- Use as display device.
- Material used is liquid crystals that are activated by electric current.

- **LDR-(Light Dependent Resister)**
- LDR most commonly used in photo sensor.
- LDR is a bidirectional resistor.
- Range of resistance 5Ω to $0.75\ M\Omega$.
- Material used for fabrication is CdS, Se.

- **Photo Conductors**
- A photo conductor or photoconductivity is an electrical and optical phenomenon where a material turns into conductive more electrically because of the electromagnetic radiation absorption like infrared light, ultraviolet light, visible light, or gamma radiation.
- Extrinsic excitation (from donor level to CB or from VB to accepter level) require lesser energy than energy gap.

- Photo conductivity equation- $\boxed{E_g = h\nu = \frac{hc}{\lambda}}$

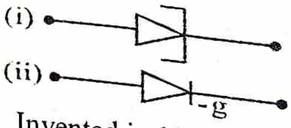
Where, h → Plank's constant

c → Speed of light in Free space.

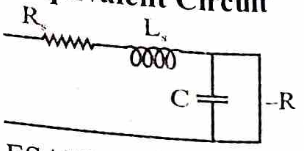
λ → Wavelength of light incident on SC

- **Tunnel Diode**
- Tunnel diode is a voltage control device.

Symbol



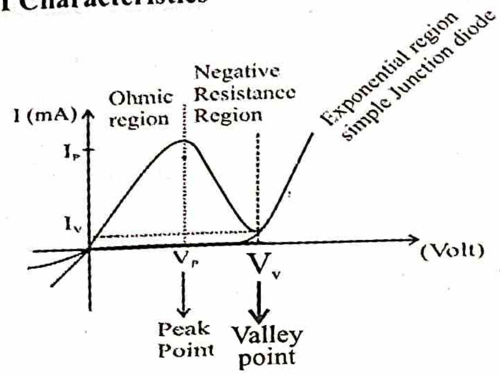
Equivalent Circuit



- Invented in 1957 by LEO ESAKI.
- Also called ESAKI Diode.
- Doping concentration. $1:10^3$ (Highly doped).
- Narrow depletion layer. (100 Å to 200 Å)
- Highly doped PN Junction.

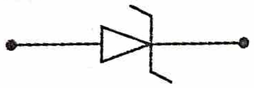
- ➢ Exhibits tunneling effect due to very narrow depletion layer.
- ➢ Low noise device.
- ➢ Fastest switch in pico second
- ➢ Negative resistance device
- ➢ Very small size and low cost and easy to fabricate.
- ➢ power dissipation negligible.
- ➢ It is works on the principle of tunneling effect.
- ➢ It is used in designing microwave oscillators, as a relaxation oscillator, in designing of pulse and switching circuits and as parametric amplifier.

- **Disadvantage-** Two terminal device therefore there is no proper isolation between input and output section
- **V-I Characteristics**



- ➢ In reverse bias tunnel diode works as resister.
- ➢ Negative resistance property lies between valley point (V_V) and peak point (V_P).
- ➢ In exponential region tunnel diode behaves as a normal diode.
- ➢ Commercial and high quality tunnel diode is made by Ge.

- **Zener diode**
- **Symbol**



Ex. of Zener Diode ⇒ IN4728, IN4729

- ➢ It is also called Zener breakdown diode.
- ➢ Heavily doped ($1:10^3$)
- ➢ Fabricated by using Si material.
- ➢ Operates on the principle of tunneling effect
- ➢ Always operates under reverse bias.
- ➢ Mainly used in voltage regulation application.
- ➢ Maintains constant voltage across a load if properly biased
- ➢ Also called constant voltage device.
- ➢ In forward bias Zener diode will be work as normal PN junction diode.
- ➢ Cut-in voltage →0.6V to 0.7V
- ➢ Zener diode commercial available → 8.5V to 300V
- ➢ For voltage regulator circuit Zener diode will work zener breakdown region

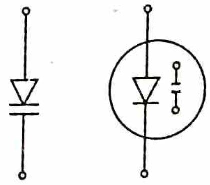
- **Zener breakdown phenomenon**
- ➢ Zener breakdown is due to large electric field.
- ➢ It is due to tearing off or rupturing off covalent bond in depletion layer.
- ➢ It's a sharp breakdown because strong Electric field immediately breaks the covalent bonds.
- ➢ No rise of temperature at the junction (Because of no collisions).
- ➢ P & N region are heavily doped.
- ➢ It is having –ve temperature coefficient of breakdown voltage.
- ➢ It is suitable for voltage regulation in the breakdown regions.
- ➢ Zener breakdown occurs below 6V.
- ➢ Zener breakdown voltage decrease with temperature increase NTC

- **Avalanche Breakdown**
- ➢ Avalanche breakdown is due to thermal collision.
- ➢ This collision is due to electron multiplication and impact ionization.
- ➢ Avalanche breakdown occurs above 6V.
- ➢ Avalanche breakdown voltage increase with temperature increase or PTC
- ➢ It's not sharp breakdown, because avalanche multiplication process takes time.
- ➢ There is rise of temperature at the junction because of collisions.
- ➢ It is not suitable for voltage regulation.
- ➢ p & n regions are lightly doped.

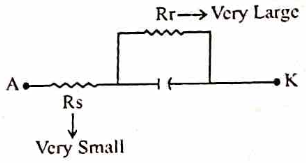
- **Tunneling phenomena :**
- ➢ It's takes place in the forward biased of zener diode.
- ➢ When the depletion layer formed very narrow from the degenerative p-type (p^{++}) and degenerative n-type (n^{++}) then there is a chance for $\bar{e}$ to escape through the depletion layer known as tunneling phenomena.

- **Varactor Diode**

Symbol



Equivalent Circuit



- ➢ It is a higher graded diode or linear graded diode.
- ➢ Always operated in reverse bias.
- ➢ Also called varicap diode.
- ➢ Low noise microwave device used.
- ➢ Transition capacitance $\boxed{C_T \propto \frac{1}{(V_{RB})^n}}$ $\boxed{C_T \propto \frac{1}{\sqrt[3]{V_{RB}}}}$

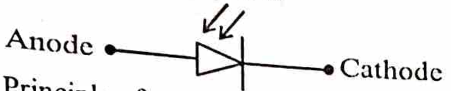
$\boxed{n = \frac{1}{3}}$ linear graded $\boxed{n = \frac{1}{2}}$ → for abrupt junction

V_{RB} = Reverse bias voltage

- **Application**

➢ Radio receiver ➢ TV receiver
➢ Tuned circuit ➢ FM Modulation ➢ Mixer
➢ Design of VCO ➢ Used in PLL
➢ Parametric Amplifier.

- **Photo Diode**
- **Symbol of photo diode**



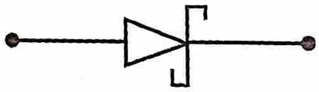
- ➢ Principle of operation is photoconductive effect.
- ➢ Photo sensitive material are CdS, Se, ZnS.
- ➢ It is also called light operated switch
- ➢ Ge-Photo diode respond to visible light while Si-photo diode respond to infrared light.
- ➢ Photo sensitive coating is provided at junction only.
- ➢ Compared to normal diode, photo diode has large depletion width obtained from lower level doping.
- ➢ It is always operated under reverse biased condition.
- ➢ As compare to normal diode it is 10 times faster, 100 times higher sensitive but power handling capacity is low.
- ➢ Magnitude of photo current increases with increase in intensity of light falling at junction.
- ➢ Current in photo diode

$$\boxed{I = I_S + I_O\left[1 - e^{V/\eta V_T}\right]}$$

Where, I_S - Short circuit current of photo diode
I_o - Reverse saturation current
V- applied voltage, $V_T \rightarrow$ Thermal Voltage

- ➢ Photo current flows from n to p region.
- ➢ Photo current is a minority carrier current.
- ➢ It does not provide gain.
- ➢ Photo current is a diffusion current.
- ➢ It is used in remote control sensor, in designing of optocouplers and to read audio track recorded on motion picture film.
- ➢ When photo diode is forward biased it behaves as a normal diode and effect of light on current is zero.
- **Avalanche Photo Diode (APD)**
- ➢ Basically a photo diode along with Avalanche effect.
- ➢ Avalanche photo diode can handle large amount of power compared to photo diode.
- ➢ Its response time is smaller than photo diode.
- ➢ Avalanche photo diode is widely used in fibre optic communication because of its high sensitivity.
- **Solar cell**
- ➢ Its principle of operation is photo Voltaic effect.
- ➢ Terminal of voltage of solar cell can't exceed the barrier potential of diode that's why an array solar cells is used to achieve higher voltage.
- ➢ We can measure terminal voltage of solar cell using voltmeter.
- ➢ Popularly used solar cells are Se cells Ni-Cd cells PbS cells.
- ➢ Ni-Cd cell are rechargeable cells used in satellites.
- ➢ It is used in automatic traffic signal lightening.
- ➢ Generally operates under open circuit condition.
- ➢ It can be operate in forward biased condition and has cut-in voltage equal to zero.
- **Opto-Couplers**
- ➢ These are optically coupled but electrically isolated.
- ➢ Opto-couplers are faster than conventional devices
- ➢ Widely used in industrial application where very good dc isolation (better than transformers) is required.
- **PIN Diode**
- ➢ It is $\boxed{p^+ - I - n^+}$ diode. 'I' represents intrinsic material
- ➢ If I is replaced by p-type then called $\boxed{p\pi n}$ diode and if I is replaced by n-type then called $\boxed{p\gamma n}$ diode.
- ➢ In PIN diode lightly doped intrinsic semiconductor is sandwiched between highly doped p and n.
- ➢ It has low response time because of high resistivity of I-region.
- ➢ It is two terminal, three layer, having single junction device
- ➢ It is always operated under reverse biased condition.
- ➢ When whole I-region is covered by depletion layer then it is called swept out condition.
- ➢ In PIN diode if whole I region is not swept out then signal loss will occur.
- ➢ It is used in handling microwave power, as microwave mixer as a duplexer in designing of transmit receive switch in designing of anti transmit-receive switch.
- **Schottky diode**

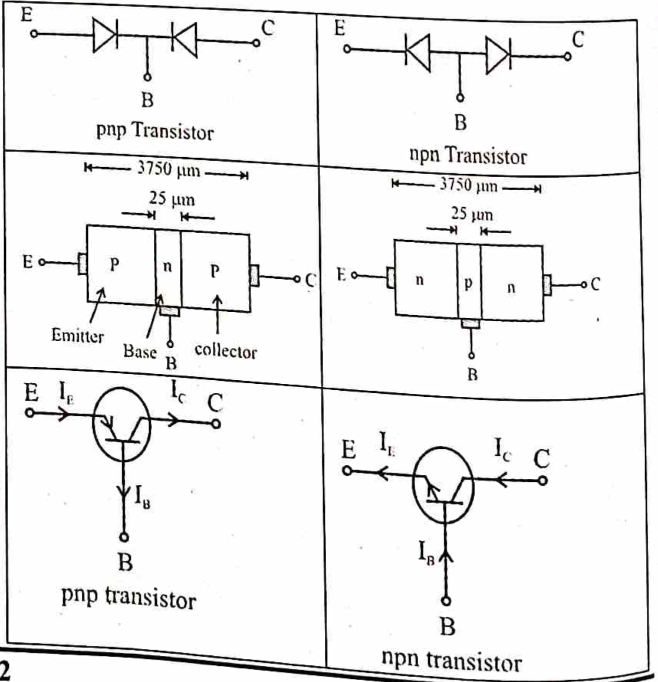
Symbol :

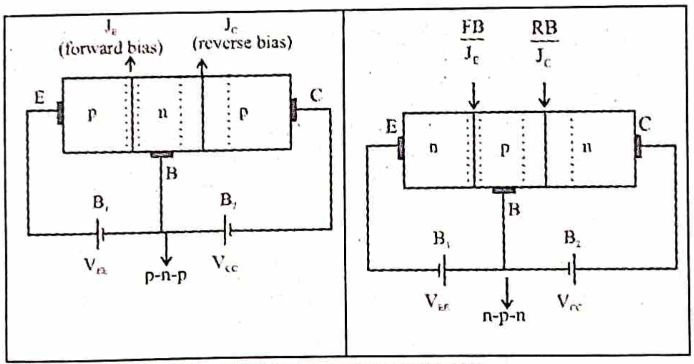


- ➢ Also known as hot-carrier diode.
- ➢ Cut-in voltage is quite small.
- ➢ It is called metal semiconductor junction.
- ➢ Switching speed is controlled by thermalization of hot-injected electrons across the barrier.
- ➢ Used to high frequency application.
- ➢ Ex. (IN5817)

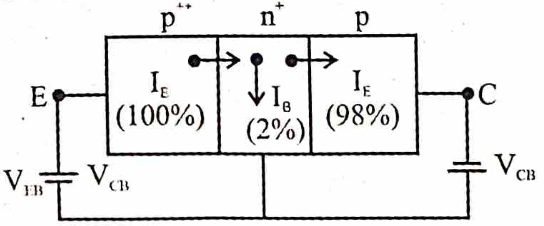
❑ Bipolar Junction Transistor

- **Symbol**




J_E
(forward bias)
J_C
(reverse bias)
E
p
n
p
C
B
B_1
B_2
V_{EE}
p-n-p
V_{CC}
FB
J_E
RB
J_C
E
n
p
n
C
B
B_1
B_2
V_{EE}
n-p-n
V_{CC}

Bipolar junction transistor (BJT)


p^{++}
n^{+}
p
E
I_E
(100%)
I_B
(2%)
I_E
(98%)
C
V_{EB}
V_{CB}
V_{CB}

- Doping level : $N_E > N_C > N_B$
- Base width should be narrower
- $\text{Area}_{(\text{Collector})}(70\%) > \text{Area}_{(\text{emitter})}(25\%) > (\text{Area})_{\text{Base}}(5\%)$

Configuration	Input node	Output node
Common base (CB)	E	C
Common collector (CC)	B	E
Common Emitter (CE)	B	C

- **Doping** E > C > B
- **Width** C > E > B
- **Characteristics–**

➢ Bipolar junction transistor was invented by William Shockley, Walter Barttain and John Bardeen bell lab in 1948.

➢ It is a Current Controlled Device. (CCD)

➢ A transistor is 3 layer, 3 terminal, 2 junction semiconductor device.

➢ It consist of either two n-type and one p-type layers of material is called n-p-n transistor or two p-type and one n-type material is called p-n-p transistor.

➢ In transistor current flow due to both majority as well as minority carrier that's why called a bipolar device.

➢ Its input impedance is low and output impedance is High.

➢ The smaller input impedance of BJT is due to forward biasing emitter base junction.

➢ In transistor all the major currents are diffusion currents.

➢ Base current is recombination current.

➢ Current conduction in p-n-p transistor is carried out by holes whereas in n-p-n transistor it is due to electrons.

➢ Higher power dissipation

➢ G×BW is constant, ($G\times BW_{BJT} > G\times BW_{FET}$)

➢ Larger gain

➢ Major application is as an amplifier.

➢ Emitter is highly doped to inject its majority carrier into the base.

➢ Emitter is provided with medium area.

➢ Base is lightly doped to reduce the recombination in base region.

➢ Transistor action takes place in the base.

➢ Base is provided with smallest area to reduce the transit time.

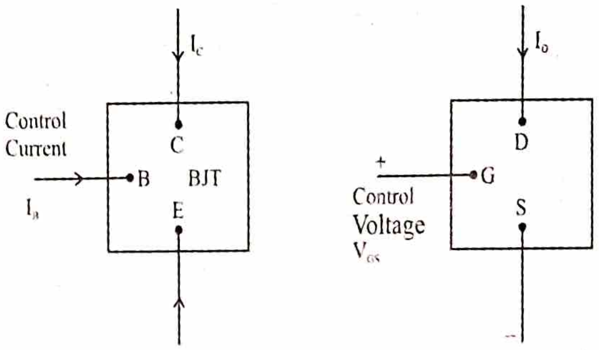
➢ Collector is moderately doped.

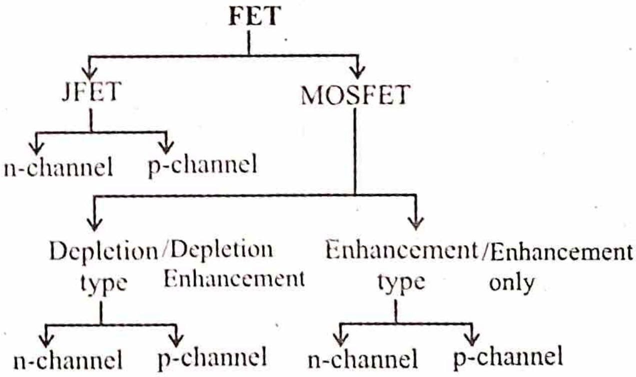
➢ Collector is provided with largest area to overcome heat dissipation (loss)

➢ Noisy device due to presence of minority carriers.

➢ Thermal stability is lesser because of larger leakage current or reverse saturation.current.

☐ FET (Field Effect Transistor)


I_C
Control
Current
C
B
BJT
E
I_B
I_D
D
+
G
Control
Voltage
V_{GS}
S


FET
JFET
MOSFET
n-channel
p-channel
Depletion/Depletion type
Enhancement
Enhancement/Enhancement type
only
n-channel
p-channel
n-channel
p-channel

➢ Majority carrier device.

➢ Smaller in size compared to BJT.

➢ Zero leakage current.

➢ Drain and source can be interchanged due to symmetrical nature of FET while BJT is asymmetrical device.

➢ In JFET channel is wedge shaped.

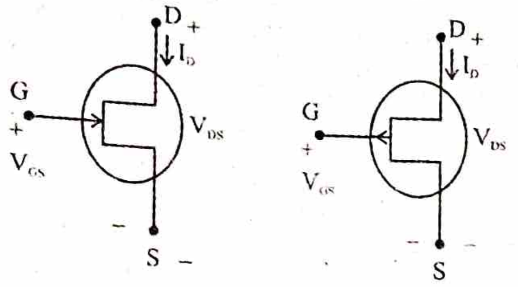
➢ Width modulation is a process of varying channel width by variation of V_{DS} .

➢ In n-channel JFET channel width is narrow near drain.

➢ Input impedance of MOSFET is greater than JFET.

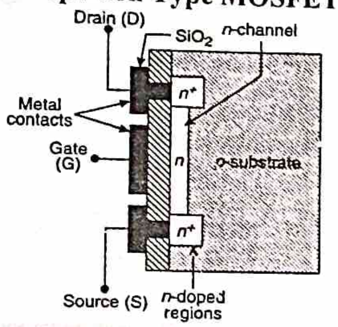
➢ FET has a major application as voltage dependent resistor.

- **JFET (Junction Field Effect Transistor)**
- **Symbol of JFET**

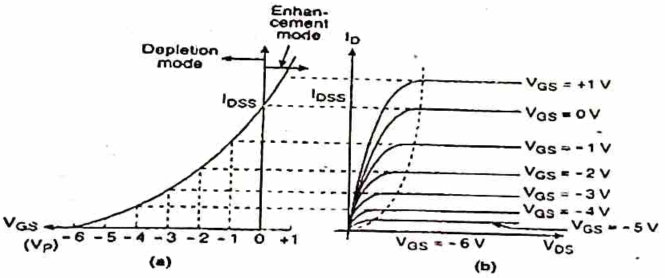

D
+
I_D
G
+
V_{GS}
V_{DS}
–
S
–
D
+
I_D
G
+
V_{GS}
V_{DS}
–
–
S

n-channel **p-channel**

- **MOSFET-** (Metal – Oxide Semiconductor Field Effect Transistor)
  - ➢ Very high input impedance and very high switching speed.
  - ➢ MOSFET is used as a Voltage controlled capacitor.
  - ➢ Also known as IGFET (Insulated Gate FET).
- **n-Channel Depletion Type MOSFET**

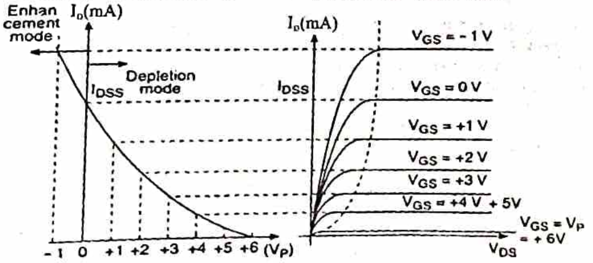

Drain (D)
SiO_2
n-channel
Metal contacts
Gate (G)
n^+
n
p-substrate
n^+
Source (S)
n-doped regions

- **Transfer Characteristics**



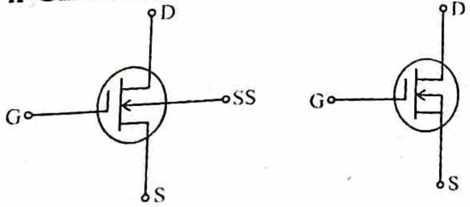
- **P-Channel Depletion type MOSFET-**

Transfer characteristic Drain characteristic

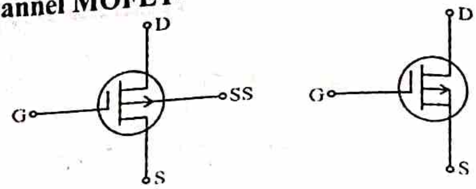


☐ Symbol for Depletion Type MOSFET

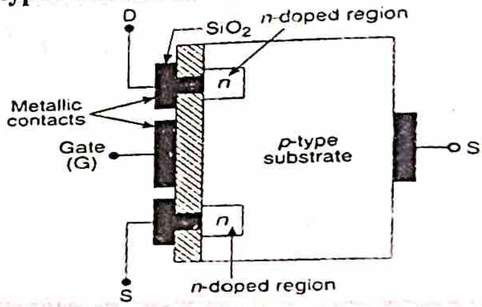
- **n-Channel MOSFET-**



- **P-Channel MOFET-**

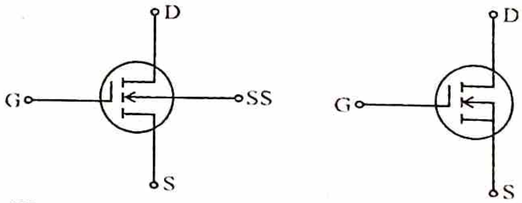


- **Enhancement Type MOSFET-** The main difference between the construction of enhancement type MOSFET and depletion type MOSFET is that the channel is not constructed in enhancement type MOSFET
- **n-type Enhancement MOSFET-**

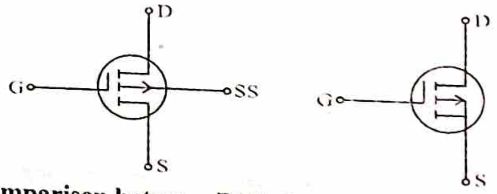

D
SiO_2
n-doped region
Metallic contacts
Gate (G)
n
p-type substrate
SS
n
S
n-doped region

☐ Symbol for Enhancement type MOSFET-

- **n-Channel-**



- **P-Channel-**

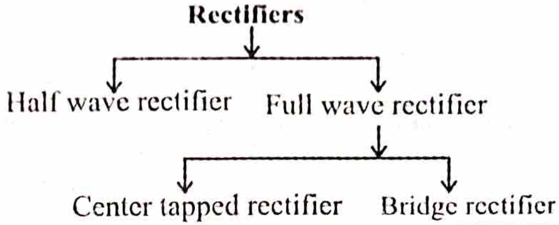


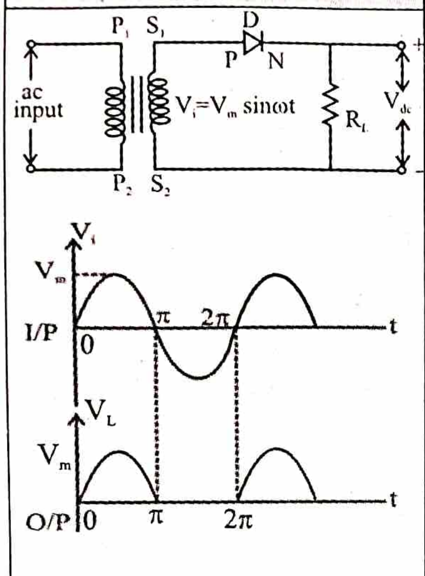
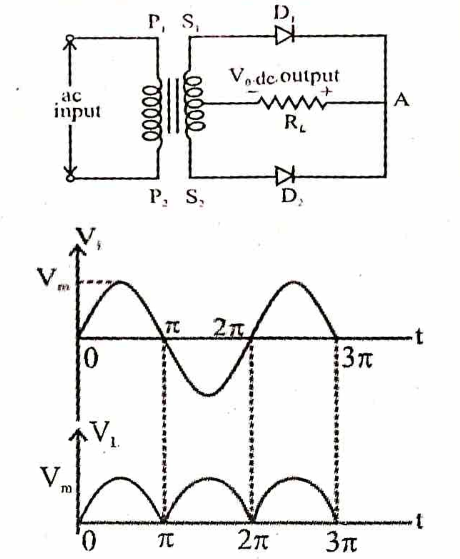
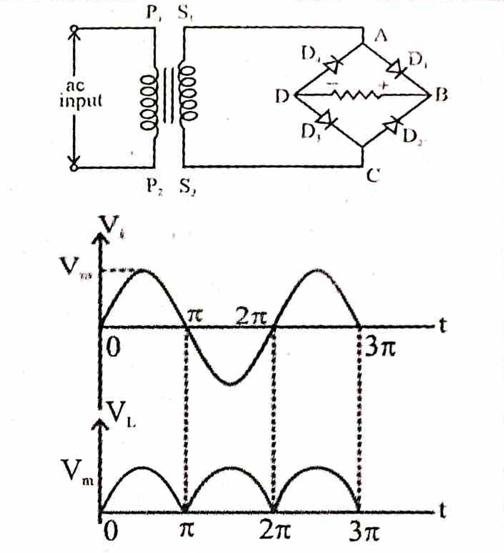
- **Comparison between BJT, JFET and MOSFET**

BJT	JFET	MOSFET
Bipolar Device	Unipolar Device	Unipolar Device
Low input impedance ($10^2\Omega$ to $10^6\Omega$)	High input impedance ($10^8\Omega$ to $10^{12}\Omega$)	Very high input impedance ($10^{10}\Omega$ to $10^{15}\Omega$)
Current controlled device	Voltage control Device	Voltage control capacitance source
Sensitivity and voltage gain high.	Sensitivity and voltage gain low	Sensitivity and voltage gain low
More noise	Less noise	Less noise
Low thermal stability	High thermal stability	High thermal stability
-------	Drain resistance is high	Drain resistance is low
for low current application	used in amplifier	used in digital circuit
Moderate speed	High speed	Very high speed

ANALOG ELECTRONICS

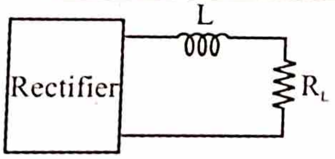
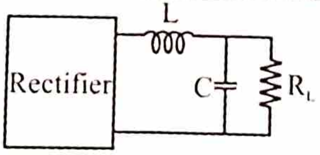
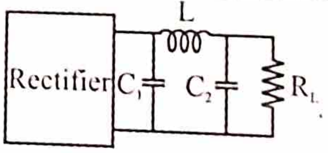
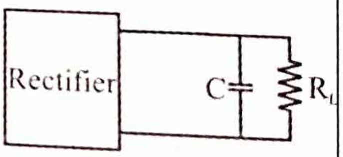
☐ **Rectifiers-** Rectifier is a device which convert ac signal to pulsating dc.


Rectifiers
Half wave rectifier
Full wave rectifier
Center tapped rectifier
Bridge rectifier

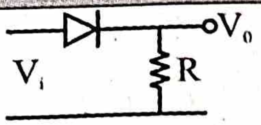
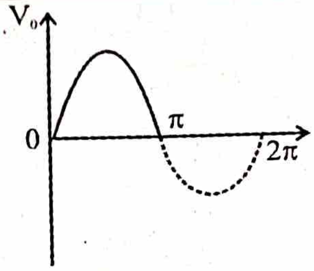
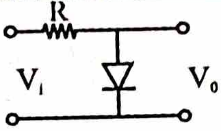
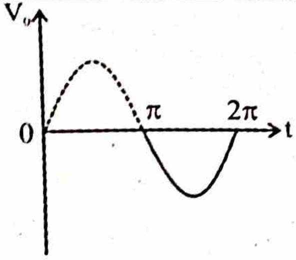
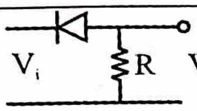
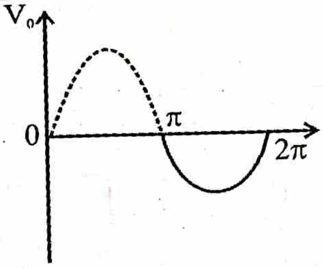
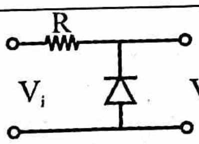
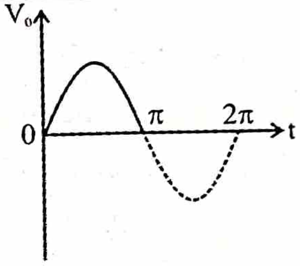
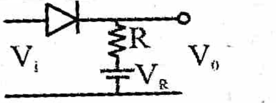
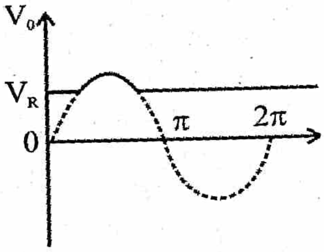
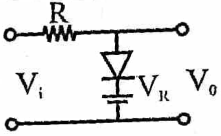
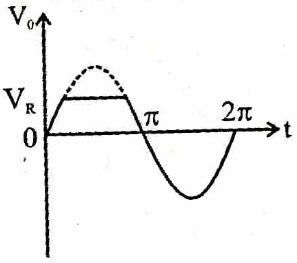
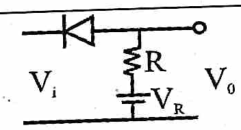
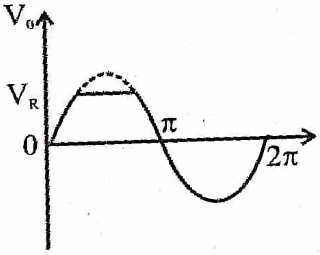
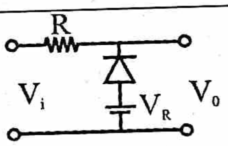
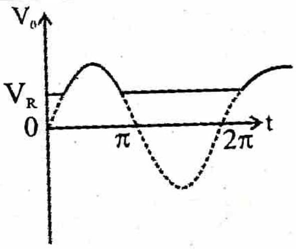
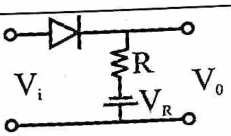
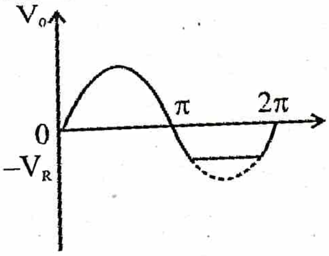
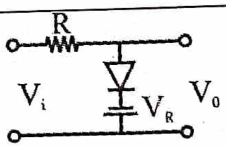
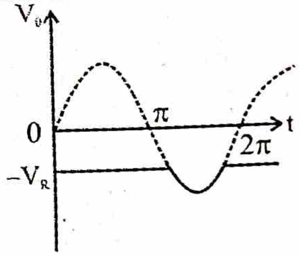
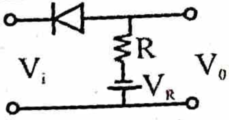
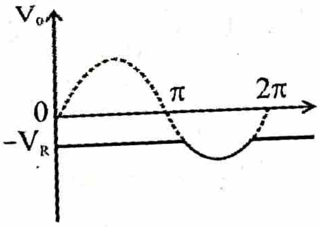
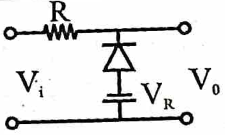
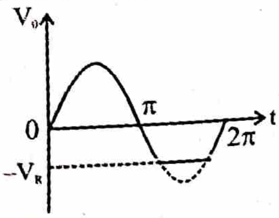
Half wave rectifier	**Full wave center tapped rectifier**	**Full wave Bridge rectifier**
 P₁ S₁ D P N ac input $V_i=V_m \sin\omega t$ R_L V_{dc} P₂ S₂ V_i V_m I/P 0 π 2π t V_L V_m O/P 0 π 2π t	 P₁ S₁ D₁ ac input V_0 dc output R_L A P₂ S₂ D₂ V_i V_m 0 π 2π 3π t V_L V_m 0 π 2π 3π t	 P₁ S₁ ac input A B C D D₁ D₂ D₃ D₄ P₂ S₂ V_i V_{ms} 0 π 2π 3π t V_L V_m 0 π 2π 3π t
• **PIV = V_m**	• **PIV = $2V_m$**	• **PIV = V_m**
• **Output dc current & voltage** • $I_{DC}=\frac{1}{2\pi}\int_0^{2\pi} i d\theta = \frac{I_m}{\pi}$, • $V_{dc}=I_{dc}.R_L=\frac{I_m}{\pi}.R_L=\frac{V_m}{\pi}$	• **Output dc current & voltage** • $I_{DC}=\frac{1}{2\pi}\left[\int_0^{\pi} i d\theta+\int_{\pi}^{2\pi} i d\theta\right]=\frac{2I_m}{\pi}$ • $V_{dc}=\frac{2V_m}{\pi}$	• **Output dc current & voltage** • $I_{DC}=\frac{1}{2\pi}\left[\int_0^{\pi} i d\theta+\int_{\pi}^{2\pi} i d\theta\right]=\frac{2I_m}{\pi}$ • $V_{dc}=\frac{2V_m}{\pi}$
• **RMS output current :** • $I_{rms}=\sqrt{\frac{1}{2\pi}\int_0^{2\pi} i^2 d\theta}$ $=\sqrt{\frac{I_m^2}{2\pi}\int_0^{2\pi}\sin^2\theta.d\theta}=\frac{I_m}{2}$ • $V_{rms}=\frac{V_m}{2}$	• **RMS output current:** • $I_{rms}=\sqrt{\left[\frac{1}{2\pi}\int_0^{2\pi} i^2 d\theta\right]}$ $=\sqrt{\left[\frac{1}{2\pi}\left\{\int_0^{\pi} i^2 d\theta+\int_{\pi}^{2\pi} i^2 d\theta\right\}\right]}=\frac{I_m}{\sqrt{2}}$ • $V_{rms}=\frac{V_m}{\sqrt{2}}$	• **RMS output current :** • $I_{rms}=\sqrt{\left[\frac{1}{2\pi}\int_0^{2\pi} i^2 d\theta\right]}$ $=\sqrt{\left[\frac{1}{2\pi}\left\{\int_0^{\pi} i^2 d\theta+\int_{\pi}^{2\pi} i^2 d\theta\right\}\right]}=\frac{I_m}{\sqrt{2}}$ • $V_{rms}=\frac{V_m}{\sqrt{2}}$
• **Ripple factor (γ)** $\gamma=\sqrt{\left(\frac{I_{rms}}{I_{dc}}\right)^2-1}$ $=\sqrt{\left(\frac{I_m/2}{I_m/\pi}\right)^2-1}=1.21$	• **Ripple factor (γ)** $\gamma=\sqrt{\left(\frac{I_{rms}}{I_{dc}}\right)^2-1}$ $=\sqrt{\frac{\left(I_m/\sqrt{2}\right)^2}{\left(2I_m/\pi\right)^2}-1}=0.48$	• **Ripple factor (γ)** $\gamma=\sqrt{\left(\frac{I_{rms}}{I_{dc}}\right)^2-1}$ $=\sqrt{\frac{\left(I_m/\sqrt{2}\right)^2}{\left(2I_m/\pi\right)^2}-1}=0.48$

• Rectification efficiency $\eta = \frac{P_{dc}}{P_{ac}} \simeq \frac{I_{dc}^2}{I_{rms}^2}$ $\eta \simeq \frac{I_{dc}^2}{I_{rms}^2} \simeq \frac{(I_m/\pi)^2}{(I_m/2)^2} \simeq 40.6\%$	**• Rectification efficiency** $\eta = \frac{P_{dc}}{P_{ac}} \simeq \frac{I_{dc}^2}{I_{rms}^2}$ $\eta \simeq \frac{(2I_m/\pi)^2}{(I_m/\sqrt{2})^2} \simeq 81.2\%$	**• Rectification efficiency** $\eta = \frac{P_{dc}}{P_{ac}} \simeq \frac{I_{dc}^2}{I_{rms}^2}$ $\eta \simeq \frac{(2I_m/\pi)^2}{(I_m/\sqrt{2})^2} \simeq 81.2\%$
• Transformer Utilization factor $TUF = \frac{P_{dc}}{P_{ac}} = \frac{I_{dc}^2.R_L}{(V_{rms}.I_{rms})}$ $= \frac{I_{dc}^2.R_L}{\frac{V_m}{\sqrt{2}}.\frac{I_m}{2}} = \frac{I_{dc}^2.R_L}{\frac{I_m^2}{2\sqrt{2}}\left(1+\frac{R_f+R_s}{R_L}\right)}$ $R_L >>> (R_f+R_s)$ $\therefore TUF = 0.287$	**• Transformer Utilization factor (TUF)** $(TUF)_p = \frac{P_{dc}}{(P_{ac})_p} = 0.812$ $(TUF)_s = \frac{P_{dc}}{(P_{ac})_{sec1}+(P_{ac})_{sec2}} = 0.573$ $TUF = \frac{(TUF)_p+(TUF)_s}{2}$ $TUF = \frac{0.573+0.812}{2} = 0.693$	**• Transformer Utilization factor (TUF)** $\bullet (TUF)_P = \frac{P_{dc}}{(P_{ac})_P} = 0.812$ $\bullet (TUF)_S = \frac{P_{dc}}{(P_{ac})_S} = \frac{P_{dc}}{(P_{ac})} = 0.812$ $TUF = \frac{(TUF)_p+(TUF)_s}{2}$ $TUF = \frac{0.812+0.812}{2} = 0.812$
• Form factor (FF) $F.F. = \frac{I_{rms}}{I_{dc}} = \frac{I_m/2}{I_m/\pi}$ $= \frac{\pi}{2} = 1.57$	**• Form factor (FF)** $F.F. = \frac{I_{rms}}{I_{dc}} = \frac{I_m/\sqrt{2}}{2I_m/\pi}$ $= \frac{\pi}{2\sqrt{2}} = 1.11$	**• Form factor (FF)** $F.F. = \frac{I_{rms}}{I_{dc}} = \frac{I_m/\sqrt{2}}{2I_m/\pi}$ $= \frac{\pi}{2\sqrt{2}} = 1.11$
• Peak factor or crest factor $PF = \frac{\text{peak value}}{\text{rms value}} = \frac{I_m}{I_m/2} = 2$	**• Peak factor or crest factor** $PF = \frac{\text{Peak value}}{\text{rms value}} = \frac{I_m}{I_m/\sqrt{2}} = 1.414$	**• Peak factor or crest factor-** $PF = \frac{\text{Peak value}}{\text{rms value}} = \frac{I_m}{I_m/\sqrt{2}} = 1.414$
• Output frequency –f	**• Output frequency-2f**	**• Output frequency-2f**

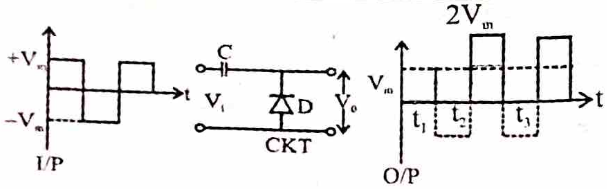
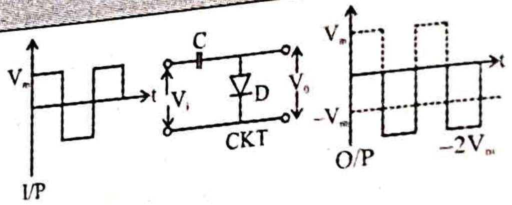
❑ Filters

Inductor filter	LC filter	CLC filter	RC filter
			
• **Ripple factor for full wave** $\gamma = \frac{R_L}{3\sqrt{2}\omega_0 L}$ • **For half wave** $\gamma = \frac{\pi R_L}{2\sqrt{2}\omega_0 L}$ L size ↑, $\gamma \propto R_L$	• **Ripple factor for full wave** $\gamma = \frac{\sqrt{2}}{3}.\frac{\lvert X_c \rvert}{\lvert X_L \rvert}$ • **For half wave** $\gamma = \frac{\pi}{2\sqrt{2}}\frac{\lvert X_C \rvert}{\lvert X_L \rvert}$	• **Ripple factor for half wave and full wave** $\gamma = \frac{\sqrt{2}\lvert X_{c_1} \rvert \lvert X_{c_2} \rvert}{R_L \lvert X_L \rvert}$	• **Ripple factor for full wave** $\gamma = \frac{1}{4\sqrt{3}f_0 R_L C}$ • **Ripple factor for half wave** $\gamma = \frac{1}{2\sqrt{3}f_0 R_L C}$

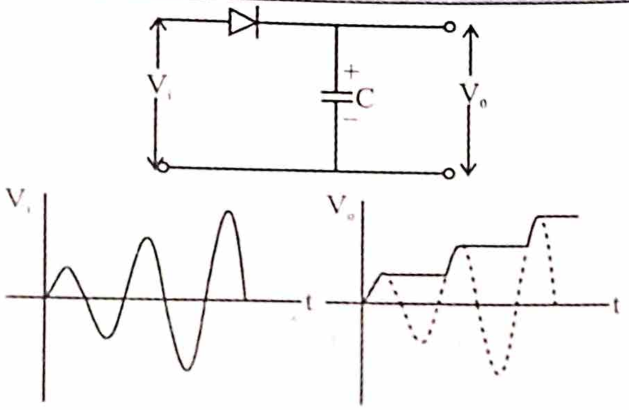
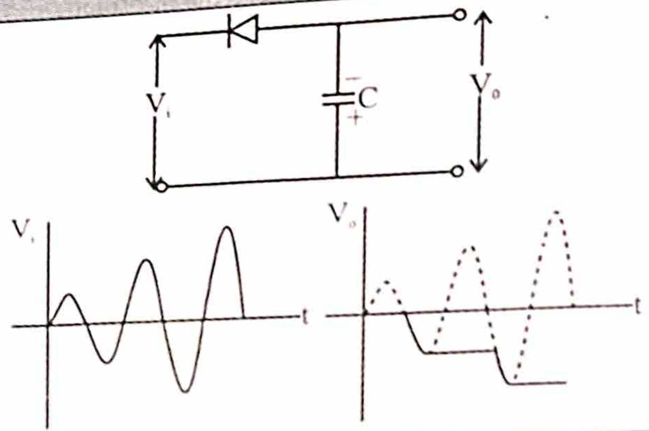
Clipper

Series clipper		Shunt clipper	
Case	**Output**	**Case**	**Output**
 $V_i<0 \rightarrow D(OFF) \rightarrow V_0=0$ $V_i>0 \rightarrow D(ON) \rightarrow V_0=V_i$		 $V_i<0 \rightarrow D(OFF) \rightarrow V_0=V_i$ $V_i>0 \rightarrow D(ON) \rightarrow V_0=0$	
 $V_i<0 \rightarrow D(ON) \rightarrow V_0=V_i$ $V_i>0 \rightarrow D(OFF) \rightarrow V_0=0$		 $V_i<0 \rightarrow D(ON) \rightarrow V_0=0$ $V_i>0 \rightarrow D(OFF) \rightarrow V_0=V_i$	
 $V_i<V_R \rightarrow D(OFF) \rightarrow V_0=V_R$ $V_i>V_R \rightarrow D(ON) \rightarrow V_0=V_i$		 $V_i<V_R \rightarrow D(OFF) \rightarrow V_0=V_i$ $V_i>V_R \rightarrow D(ON) \rightarrow V_0=V_R$	
 $V_i<V_R \rightarrow D(ON) \rightarrow V_0=V_i$ $V_i>V_R \rightarrow D(OFF) \rightarrow V_0=V_R$		 $V_i<V_R \rightarrow D(ON) \rightarrow V_0=V_R$ $V_i>V_R \rightarrow D(OFF) \rightarrow V_0=V_i$	
 $V_i<-V_R \rightarrow D(OFF) \rightarrow V_0=-V_R$ $V_i>-V_R \rightarrow D(ON) \rightarrow V_0=V_i$		 $V_i<-V_R \rightarrow D(OFF) \rightarrow V_0=V_i$ $V_i>-V_R \rightarrow D(ON) \rightarrow V_0=-V_R$	
 $V_i<-V_R \rightarrow D\ (ON) \rightarrow V_0=V_i$ $V_i>-V_R \rightarrow D(OFF) V_0 \rightarrow -V_R$		 $V_i<-V_R \rightarrow D(ON) \rightarrow V_0=-V_R$ $V_i>-V_R \rightarrow D(OFF) \rightarrow V_0=V_i$	

☐ Clampers

Positive clamper	Negative clamper
 2V_m +V_m −V_m t I/P C V_i D V_o CKT V_m t₁ t₂ t₃ t O/P $0 \to t$: D(OFF), start with t, $C \to$ uncharged $t_1 \to t_2$: D(ON) $C \to$ charges to V_m, $V_0=0$ $t_2 \to t_3$: D (OFF), $V_0=2V_m$	 V_m t I/P C V_i D V_o CKT V_m −V_m t O/P −2V_m $0 \to t_1$ $C \to$ get charged to V_m, D (ON) $V_0=0$ $t_1 \to t_2$: D (OFF) $V_0 = -2V_m$

☐ Peak detectors

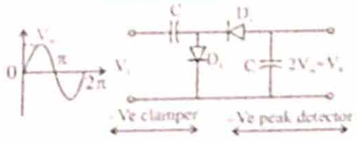
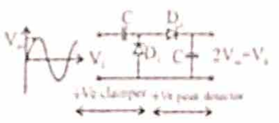
Positive peak detector	Negative peak detector
 V_i + C − V_o V_i t V_o t	 V_i − C + V_o V_i t V_o t

☐ Voltage Multiplier

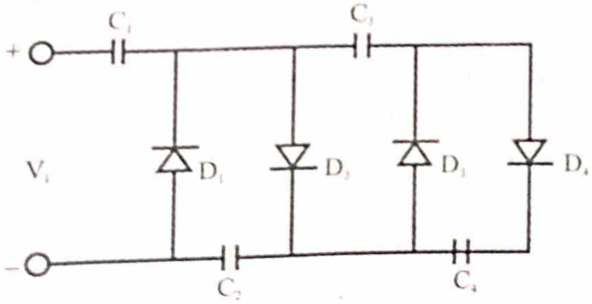
Input is an AC wave form of peak V_m and output is DC Voltage which is an integer multiple of peak AC input

$$V_0 = 2V_m, 3V_m, 4V_m$$

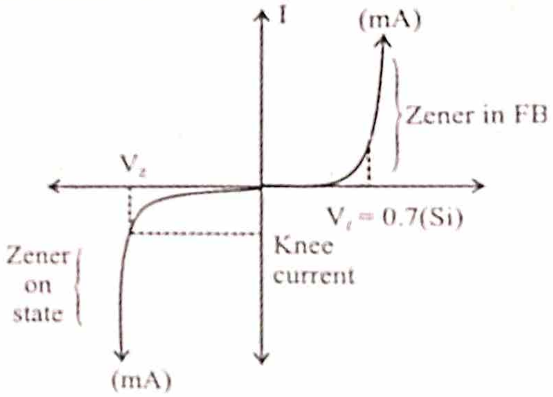
☐ Voltage doublers

-ve voltage doubler	+ve voltage doubler
 V_m 0 π 2π V_i C D D₁ C 2V_m-V_i -Ve clamper -Ve peak detector	 V_m V_i C D D₁ C 2V_m-V_i +Ve clamper +Ve peak detector

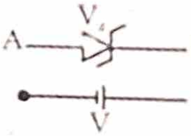
☐ Voltage Tripler/Quadrupler


C₁
C₃
+
V_i
D₁
D₂
D₃
D₄
−
C₂
C₄

☐ Zener diode

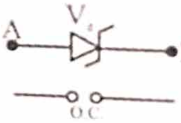


Case I



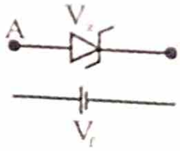
$\Rightarrow V > V_z$
ON-state

Case II



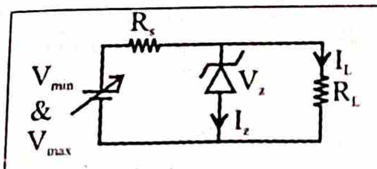
$\Rightarrow 0 < V < V_z$
OFF-state

Case III



V→F.B.

Zener Voltage Regulator



$$(I_s)_{min} = \frac{(V_i)_{min} - V_z}{R_s}$$

$$(I_s)_{max} = \frac{(V_i)_{max} - V_z}{R_s}$$

Case I: When V_i-Variable & R_L-fixed

$(I_z)_{min} = (I_s)_{min} - (I_L)$

$(I_z)_{max} = (I_s)_{max} - (I_L)$

Case II: When V_i-variable & R_L-variable

$(I_z)_{min} = (I_s)_{min} - (I_L)_{max}$

$(I_z)_{max} = (I_s)_{max} - (I_L)_{min}$

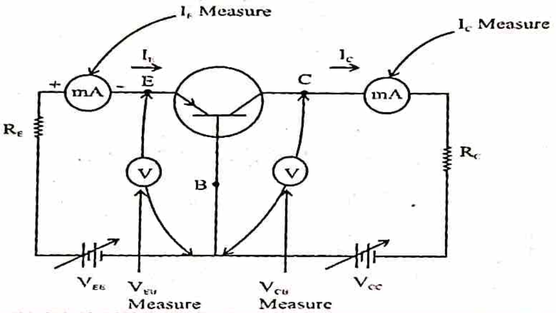
Case III: When V_i-fixed & R_L-variable

$(I_z)_{min} = (I_s) - (I_L)_{max}$

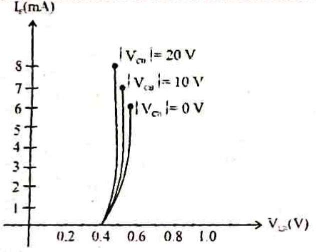
$(I_z)_{max} = (I_s) - (I_L)_{min}$

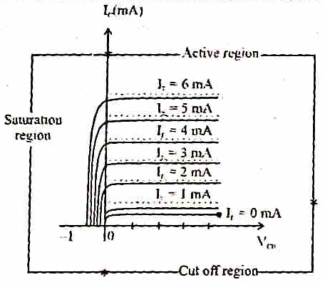
Bipolar Junction Transistor

Common base configuration



Input **Output**





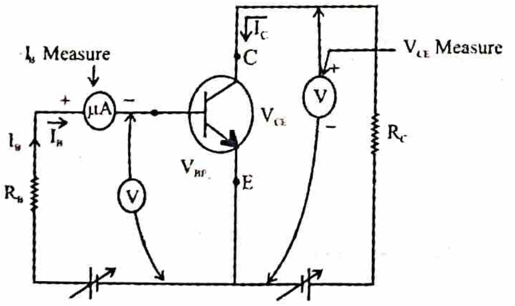
- $\alpha = \frac{I_C}{I_E}$; $\alpha(0.90 \text{ to } 0.99)$
- $I_C = \alpha I_E + I_{CBO}$

$\boxed{I_E = I_B + I_C + I_{CBO}}$ or $\boxed{I_E = I_B + I_C}$

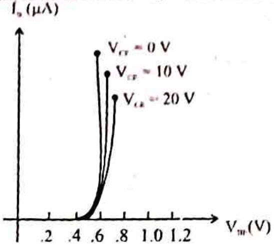
Where, I_E = Emitter Current, I_B = Base current,
I_C = Collector current,
I_{CBO} = Collector to base leakage current

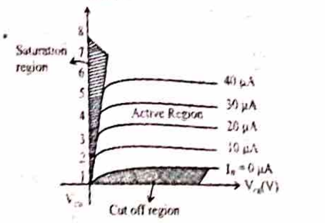
$\boxed{I_B \simeq 2\% \text{ of } I_E}$ $\boxed{I_C = 98\% \text{ of } I_E}$

Common Emitter Configuration



Input **Output**





$$\beta = \frac{I_C}{I_B}; \beta \rightarrow (20 \text{ to } 500)$$

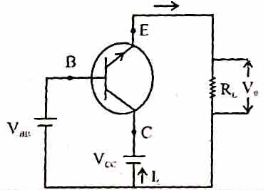
$$\beta = \left(\frac{\alpha}{1-\alpha}\right) \text{ or } \alpha = \frac{\beta}{1+\beta}$$

$$\& \ \frac{1}{(1-\alpha)} = 1+\beta$$

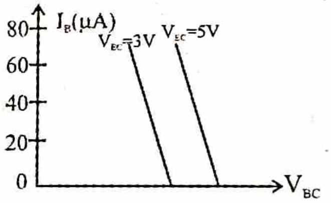
- $I_c = \beta I_B + I_{CEO}$

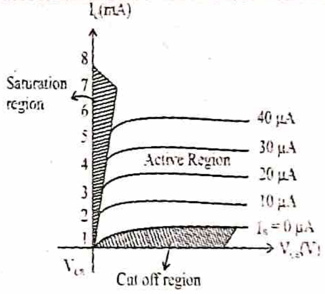
➢ β range from 20 to 500

Common Collector Configuration



Input **Output**





$$\gamma = \frac{I_E}{I_B} \text{ or } \gamma = 1+\beta = \frac{1}{1-\alpha}$$

- Total emitter current

$$I_E = (1+\beta)I_B + (1+\beta)I_{CBO}$$

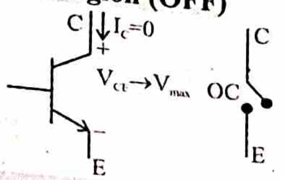
➢ Common collector configuration also known as Emitter follower.

➢ Voltage gain is always less than one so never used for amplification purpose.

➢ Power dissipation is maximum in active region and minimum in cut-off region and saturation region.

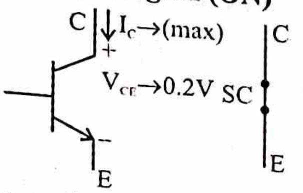
Mode	J_{EB}	J_{CB}	Property	Application
Saturation	forward bias	forward bias	Very low resistance	'ON Switch'
Cut-off	Reverse bias	Reverse bias	Very High Resistance	'Off Switch'
Active	forward bias	Reverse bias	Excellent transistor Action	Amplifier
Reverse Active	Reverse bias	forward bias	Poor transistor Action	Attenuator

- **Cut-off region (OFF)**



Digital Application
Open circuit switch
OFF switch
OFF state
Zero state

- **Saturation region (ON)**



Digital Application
Short circuit switch
ON switch
ON state
1 state

- ➢ In transistor under active region, both the depletion layers will be penetrating more into the base.
- ➢ ECL (Emitter Coupled Logic) is the fastest logic gate and is operated in the active mode but not as a switch.
- ➢ In NPN transistor, current is dominated by the flow of electrons.
- ➢ In PNP transistor current is mainly due to holes.
- ➢ NPN transistor is faster than the PNP $(\mu_n > \mu_p)$.
- ➢ Arrow mark indicates direction of emitter current when emitter base junction is forward bias.
- ➢ NPN and PNP transistor called complementary transistor.

Current in BJT

- **Total collector current**

$\boxed{I_C = \beta I_B + I_{CEO}}$ $\boxed{I_C = \beta I_B + (1+\beta) I_{CBO}}$

I_{CEO} = Collector to emitter leakage current.

$\boxed{I_{CEO} = (1+\beta) I_{CBO}}$

$\beta \to$ Current gain of common emitter.

- ➢ Power dissipation in a transistor

$P_T = |I_C| \times |V_{CE}|$

Where, I_C = Collector current; V_{CE} = collector to emitter voltage.

- ➢ Power dissipation in saturation and cut off region is almost zero.
- ➢ Power dissipation is maximum in active region.
- ➢ Emitter Cut off current

$I_{CBO} \cong I_{CO}$ but actually it is given slightly greater than I_{CO}

- ➢ Base Cut off current

$\boxed{I_{CEO} = (1+\beta) I_{CO}}$ $I_{CO} \to$ reverse saturation current across reverse biased collector junction.

$\boxed{I_{CEO} > I_{CBO} > I_{CO}}$

- **Current gain of common collector**

$$\boxed{\gamma = \frac{I_E}{I_B} = \beta + 1 = \frac{1}{1-\alpha}}$$

β for dc analysis is greater than β for ac Analysis.

- **Emitter injection efficiency**

$\boxed{\gamma_E = \frac{i_{Ep}}{i_{Ep} + i_{En}}}$ for p-n-p $\boxed{\gamma_E = \frac{i_{En}}{i_{Ep} + i_{En}}}$ for n-p-n

Where, i_{Ep} = Emitter current due to holes.
i_{En} = Emitter current due to electrons.

- **Base transport factor**

$\boxed{B = \frac{i_C}{i_{Ep}}}$ for p-n-p $\boxed{B = \frac{i_C}{i_{En}}}$ for n-p-n

- ➢ Current gain α in term of γ_E and B $\boxed{\alpha = B\gamma_E}$
- ➢ Value of γ_E and B is very close to 1 and in ideal condition it is 1.
- ➢ In diffusion transistor base current is only due to diffusion.
- ➢ In drift transistor base current is due to diffusion and drift phenomenon.

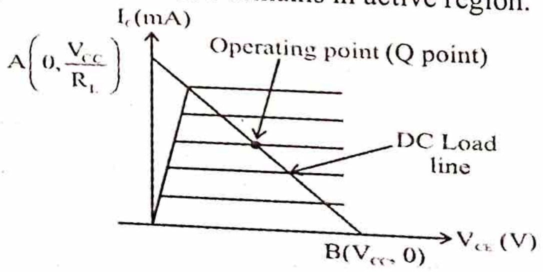
- **Early Effect**

- ➢ Increase in depletion region width due to increase in reverse biased across collector base junction is called Early Effect.
- ➢ Due to early effect, effective base width decreases.
- ➢ Due to early effect, α increases by little amount but β increases by large amount.

Char.	**CB confi.**	**CE confi.**	**CC confi.**
Input Resistance	Very low (20 Ω)	Low (1 kΩ)	Very large (1 MΩ)
Output Resistance	Very Large (1 MΩ)	High (10 kΩ)	Low (1 kΩ)
Current Gain	Less than unity	High (100)	High (100)
Voltage Gain	Large (1000)	High (100)	Less than unity
Power Gain	Medium	Very Large	Less
Leakage Current	Very small	Very Large	Very Large
Phase Shift	0°	180°	0°
Application	for Voltage and power Amplification	for Voltage, Current and power Amplification	for Better Impedance matching.

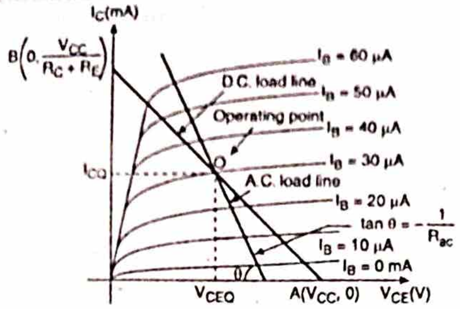
- **DC Load Line**

DC Load Line is the Locus of all possible operating point at which BJT remains in active region.



- ➢ Slope of DC load line - $\frac{-1}{R_L}$

- **AC load line**



➢ Slope of AC load line - $\frac{-1}{R_{ac}}$

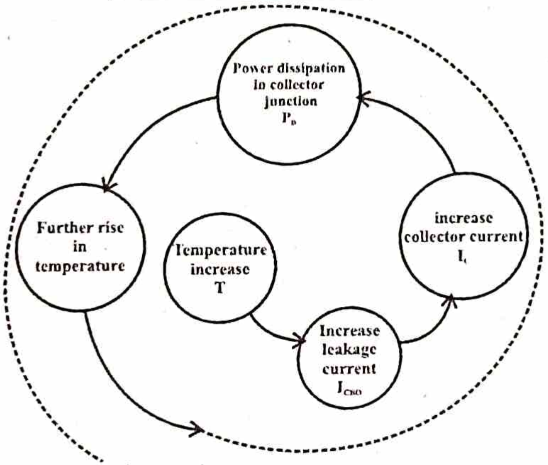
➢ Slope of AC load line is greater than slope of DC load line

$I_B < I_{Csat}/\beta$ (Active region).

$I_B > I_{Csat}/\beta$ (Saturation region).

$\boxed{I_{Cmax} = \frac{V_{CC}}{R_C}}$ [where $V_{CE} = 0$ at saturation)

- **Thermal Runaway-** Transistor can be seriously affected by the temperature rise. The two of the most temperature sensitive quantities are V_{BE} and I_C We know that $\boxed{I_C = \beta I_B + (1+\beta) I_{CBO}}$


Power dissipation in collector junction P_D
increase collector current I_C
Increase leakage current I_{CBO}
Temperature increase T
Further rise in temperature

Thermal runaway

- **Thermal resistance –**

$\boxed{\theta = \frac{T_j - T_A}{P_D}}$ (°C/Watt or °K/Watt)

T_j → Collector junction temperature

T_A → Ambient temperature in Kelvin

P_D → Power dissipated across collector junction

- **Condition to avoid thermal run away**

$$\boxed{(V_{CE})_Q \le \frac{V_{CC}}{2}}$$

- **Bias Stabilization**

➢ If I_{CO}, V_{BE} and β changes simultaneously then net change in I_C.

$$\boxed{\Delta I_C = \frac{\partial I_C}{\partial I_{CO}} \Delta I_{CO} + \frac{\partial I_C}{\partial V_{BE}} \times \Delta V_{BE} + \frac{\partial I_C}{\partial \beta} \Delta \beta}$$

Where, $\frac{\partial I_C}{\partial I_{CO}} = S$ (Current stability factor)

$\frac{\partial I_C}{\partial V_{BE}} = S'$ (Voltage stability factor)

$\frac{\partial I_C}{\partial \beta} = S_\beta = S''$ (Amplification stability factor)

$\boxed{S_{ideal} = 1}$ Alternate evaluation of $\boxed{S = \frac{1+\beta}{1-\beta \frac{\partial I_B}{\partial I_C}}}$

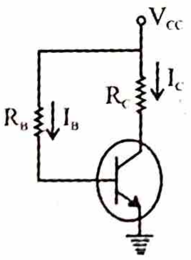
➢ Practically S should be less than 20.

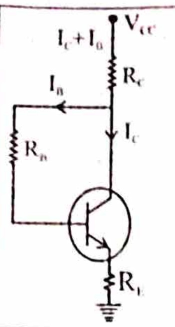
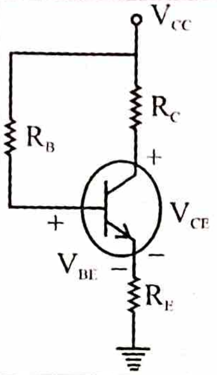
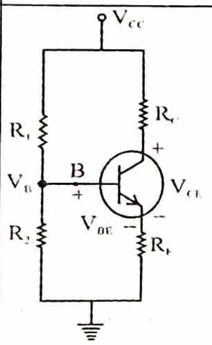
➢ Needs of biasing of BJT-

i. To operate the BJT in active region so that it can be used as amplifier.

ii. To maintain I_C stable so that the operating point does not drift and thermal run away does not happen.

❑ Different type of Transistor Biasing Circuit

Types	Circuit diagram	Formula	Specifications
Fixed biased circuit		$\boxed{I_B = \frac{V_{CC} - V_{BE}}{R_B}}$ $\boxed{I_C = \beta I_B}$ $\boxed{I_C = \frac{V_{CC} - V_{CE}}{R_C}}$ $\boxed{V_{CE} = V_{CC} - I_C R_C}$	• The circuit is simple • Only one resistor R_B is required • Biasing conditions are set easily • Poor stability • No loading effect at BE junction • High stability factor $(S = 1+\beta)$ • Strong chances of thermal run away.

Collector to Base Bias circuit	 V_{CC} I_C+I_B R_C I_B I_C R_B R_E	$\boxed{I_B = \frac{V_{CC}-V_{BE}}{R_B+\beta(R_C+R_E)}}$ $\boxed{I_C=\beta I_B}$ $\boxed{I_E=(\beta+1)I_B}$ $\boxed{V_{CE}=V_{CC}-(I_C+I_B)R_C}$	• The circuit is simple • Stability factor $S<(\beta+1)$ • Better thermal stability than the fixed bias • Doesn't provide good stabilization • Provides negative feedback
Emitter Bias or Self Bias circuit	 V_{CC} R_C R_B + V_{CE} + − V_{BE} − R_E	$\boxed{I_B = \frac{V_{CC}-V_{BE}}{R_B+(\beta+1)R_E}}$ $\boxed{I_C=\beta I_B}$ $\boxed{V_{CE}=V_{CC}-I_C(R_C+R_E)}$	• Provides excellent bias stability in spite of change in β or temperature • Uses both positive and negative supply voltage • To obtained a reasonable estimate of the key dc values in an ammeter bias circuit analysis is quite easy.
Potential Divider Bias Circuit	 V_{CC} R_1 R_C B + V_B + V_{CE} V_{BE} − − R_2 R_E	$\boxed{I_B = \frac{V_{th}-V_{BE}}{R_{th}+(\beta+1)R_E}}$ $\boxed{I_C=\beta I_B}$ $\boxed{I_E=(\beta+1)I_B}$ $\boxed{V_{CE}=V_{CC}-I_C(R_C+R_E)}$ $\boxed{R_{th}=\frac{R_1R_2}{R_1+R_2}}$ $\boxed{V_{th}=\frac{R_2}{R_1+R_2}V_{CC}}$	• Excellent stabilization because I_C is independent of transistor parameters (β) • Stability factor S = 1 • Maximum possible thermal stability

- **Darlington Amplifier**

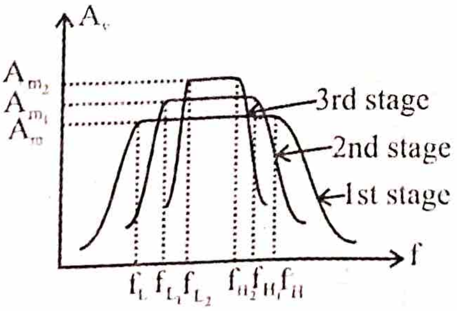
➢ Known as super β circuit ➢ Used as buffer.

➢ Used where very high input impedance and high current gain required.

➢ Cascade of two common collector amplifier or Cascade of two common drain amplifier.

Amplifier type	**Configuration**
CE-CC	Cascade amplifier
CC-CC	Darlington pair
CE-CB	Cascode amplifier

❑ Frequency Response of Multistage



- When amplifier are non identical then

$$f_L^* = 1.1\sqrt{f_{L_1}^2+f_{L_2}^2+....f_{L_n}^2} \quad \& \quad \frac{1}{f_H^*}=1.1\sqrt{\frac{1}{f_{H_1}^2}+\frac{1}{f_{H_2}^2}+...\frac{1}{f_{H_n}^2}}$$

- Rise time $t_r^* = 1.1\sqrt{t_{r_1}^2+t_{r_2}^2+...t_{r_n}^2}$

Low frequency region	• Behave as high pass filter • Gain in low frequency region as $A_f = \frac{A_m}{\sqrt{1+\left(\frac{f_L}{f}\right)^2}}$ • Slope of low frequency region cover will be look like $\theta = \tan^{-1}\left(\frac{f_L}{f}\right)$
High frequency region	• Gain in high frequency region as $A_f = \frac{A_m}{\sqrt{1+\left(\frac{f}{f_H}\right)^2}}$

- Slope $\theta = \tan^{-1}\left(\frac{f}{f_H}\right)$

➢ Upper cut-off frequency of overall configuration is-

$$f_H^{*} = f_H\sqrt{2^{1/n}-1}$$

➢ Lower cut-off frequency of overall configuration is-

$$f_L^{*} = \frac{f_L}{\sqrt{2^{1/n}-1}}$$

- **Multistage Amplifier**

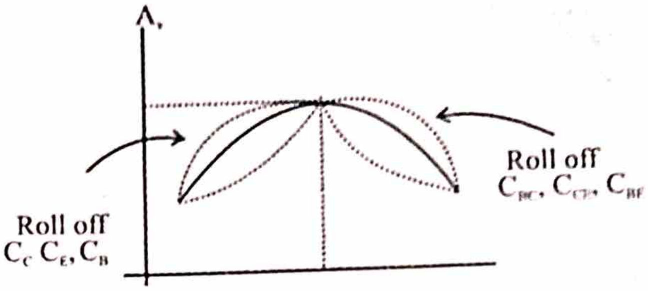
➢ Overall gain $A_v = \frac{V_0}{V_i} = A_1A_2A_3A_4 \ldots A_n$

➢ Power gain $A_p = 10\log\frac{P_{out}}{P_{in}}\Big|_{dB}$

➢ Voltage gain $A_v = 20\log\frac{V_{out}}{V_{in}}\Big|_{dB}$

➢ Current gain $(A_I) = 20\log\frac{I_{out}}{I_{in}}\Big|_{dB}$

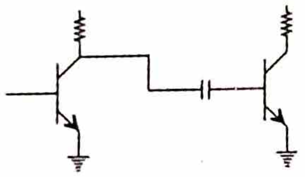
- **Frequency response of an Amplifier**



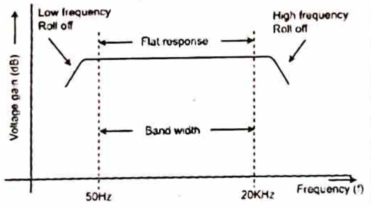
➢ The response below to resonate frequency rolls of (Reduce) due to external capacitor (C_B, C_E, C_C) added to the amplifier.

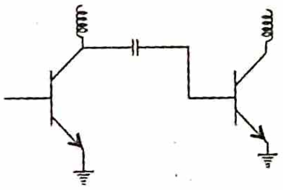
➢ Similarly the gain corresponding to above frequency of resonate also reduces the region is internal generated capacitor such as C_{BE}, C_{BC}, C_{CE}, Miller capacitor & wiring capacitor.

❑ Coupling Scheme :

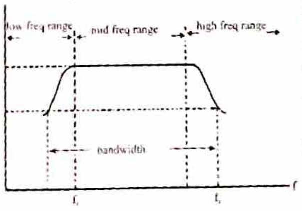
<table>
<tr><th>RC Coupling</th><th>LC Coupling</th><th>Transformer Coupling</th><th>Direct Coupling</th></tr>
<tr>
<td>


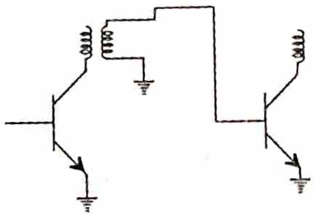
•Frequency response



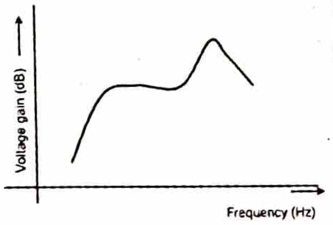
- Small signal passes from one stage to other.
- If F ↑→ CC→ ↓ loading effect ↓→ Gain ↓
- It provide less frequency distortion.
- Overall gain is small.
- It is provide poor impedance matching.
- Used in public addressing system.
</td>
<td>


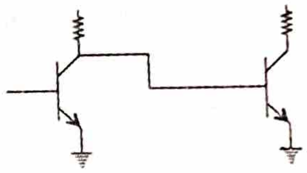
•Frequency response



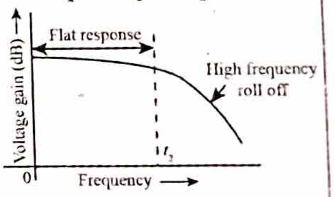
- It's operated at low collector supply voltage.
- The output is obtained by $V_0 = X_L \cdot I_C = I_C \cdot 2\pi f C$ means dependent on two frequency so low frequency provide low output that will be not sufficient for any electric circuit so it is suitable only at frequency above 20 kHz.
</td>
<td>


•Frequency response



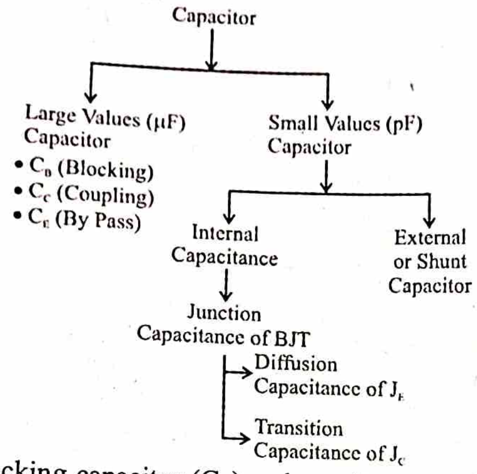
- It is in last stage of multistage amplifier.
- Frequency response look like RC couple Amplifier.
- Small flat response.
- Provide higher voltage gain.
- It is provide excellent matching means maximum power transfer to load.
</td>
<td>


•Frequency response



- To operate in low frequency region.
- The main advantage is the lower frequency operation.
- Limited frequency Range.
</td>
</tr>
</table>

☐ Capacitors


Capacitor
Large Values (μF) Capacitor
• C_B (Blocking)
• C_c (Coupling)
• C_E (By Pass)
Small Values (pF) Capacitor
Internal Capacitance
External or Shunt Capacitor
Junction Capacitance of BJT
Diffusion Capacitance of J_E
Transition Capacitance of J_C

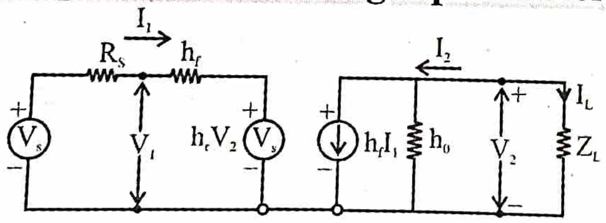
- Blocking capacitor (C_B) and coupling capacitor (C_c) provide → DC isolation to biasing circuit.
- Bypass capacitor (C_E) →decrease voltage gain.

Capacitor	Lower cut off frequency
C_C	$\boxed{\dfrac{1}{2\pi C_C(R_C+R_L)}}$
C_E	$\boxed{\dfrac{g_m}{2\pi C_E}}$
C_B	$\boxed{\dfrac{1}{2\pi C_B(R_S+R_i)}}$

- **Typical π - model parameter values for CE transistor.**

Parameter	Value	Parameter	Value
$r_{bb'}$	100Ω	r_π	1 kΩ
r_0	80kΩ	r_μ	4 MΩ
C_μ	3pf = C_C	C_π	100 pf = C_e
g_m	50 mS		

☐ Amplifier circuit using h-parameters


I₁
R_S
h_r
+
−
V_s
V_I
h_rV₂
V_s
I₂
h_fI₁
h₀
V₂
I_L
Z_L

$V_1 = h_iI_1 + h_rV_2$, $I_2 = h_fI_1 + h_0V_2$

- **Current gain**

$$A_I = \frac{I_2}{I_I} = \frac{-h_f}{1+h_0Z_L}$$

- **Input impedance**

$$Z_i = \frac{V_I}{I_I} = h_I + h_rR_LA_I$$

- **Voltage gain** $A_v = \dfrac{V_2}{V_I} = \dfrac{A_IR_s}{Z_i \times R_s}$

- **Output admittance**

$$Y_0 = \frac{I_2}{V_2} = h_0 - \frac{h_fh_r}{h_i+R_s}$$

■ Conversion formulae for h-parameter

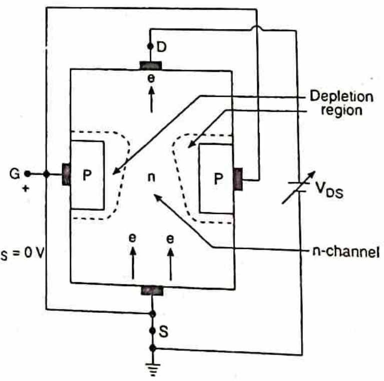
CE to CB	CB to CE	CE to CC
$h_{ib} = \dfrac{h_{ie}}{1+h_{fe}}$	$h_{ie} = \dfrac{h_{ib}}{1+h_{fb}}$	$h_{ic} = h_{ie}$
$h_{fb} = \dfrac{-h_{fe}}{1+h_{fe}}$	$h_{fe} = \dfrac{-h_{fb}}{1+h_{fb}}$	$h_{fc} = -(1+h_{fe})$
$h_{rb} = \dfrac{h_{ie}.h_{oe}}{1+h_{fe}} - h_{re}$	$h_{re} = \dfrac{h_{ib}.h_{ob}}{1+h_{fb}} - h_{rb}$	$h_{rc} = 1 - h_{re}$
$h_{ob} = \dfrac{h_{oe}}{1+h_{fe}}$	$h_{oe} = \dfrac{h_{ob}}{1+h_{fb}}$	$h_{oc} = h_{oe}$

■ Typical value of h-parameter

h-parameter	C.E	CC	CB
h_i=h_{ic}	1100Ω	1100 Ω	21.6 Ω
h_f=h_{ie}	50	–51	–0.98
h_r=h_{ie}	2.5×10^{-4}	$\simeq 1$	2.9×10^{-4}
h_0	25×10^{-6} mho	24×10^{-6} mho	0.49×10^{-6} mho

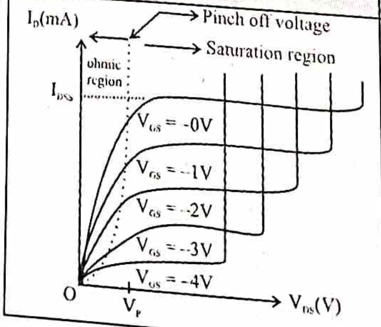
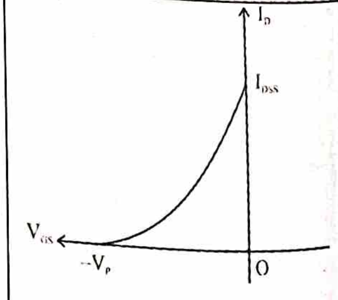
☐ Field Effect Transistor (FET)

- **n-channel Junction field effect transistor (JFET)**

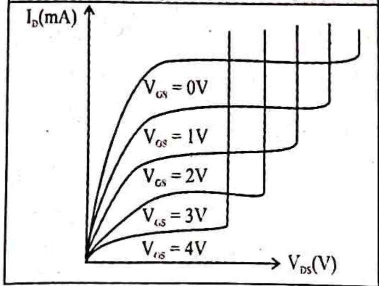
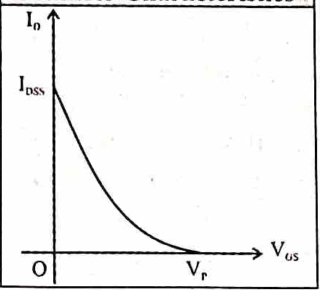

D
e
Depletion region
G
+
P
n
P
V_DS
V_GS = 0 V
e
e
n-channel
S

➢ In JFET Gate always reverse biased.

➢ After pinch off JFET operate as constant current source in which voltage vary.

Drain characteristics	Transfer characteristics
	

- **p-Channel JFET**

Drain characteristics	Transfer Characteristics
	

- **Parameters of JFET**

Parameters	Range	Parallel connection of two FETs
Transconductance- $g_m=\left.\frac{\Delta I_D}{\Delta V_{GS}}\right\vert_{V_{DS}=\text{Constant}}$	0.1-10 amp/V	$g_m=g_{m_1}+g_{m_2}$
Drain Resistance $r_d=\left.\frac{\Delta V_{DS}}{\Delta I_D}\right\vert_{V_{GS}=\text{Constant}}$	100kΩ-500kΩ	$r_d=\frac{r_{d_1}r_{d_2}}{r_{d_1}+r_{d_2}}$
Amplification factor $\mu=\left.\frac{\Delta V_{DS}}{\Delta V_{GS}}\right\vert_{I_D=\text{Constant}}$	2.5-150 (Unitless)	$\mu=\frac{\mu_1 r_{d_2}+\mu_2 r_{d_1}}{\mu_1+\mu_2}$
ΔV_{GS} - Change in gate voltage, ΔV_{DS} - Change in Drain voltage, ΔI_D - Change in drain current.		

■ Relation between three parameters of JFET-

- ➢ Transfer characteristic equation,

$$\boxed{I_{DS}=I_{DSS}\left(1-\frac{V_{GS}}{V_P}\right)^2}$$

Where, I_{DSS} -Saturation Current at $V_{GS}=0$
V_P- Pinch off Voltage,
I_{DS} - Saturation current at any V_{GS}

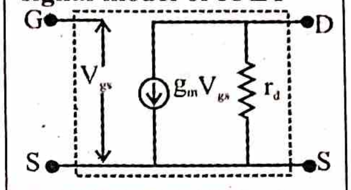
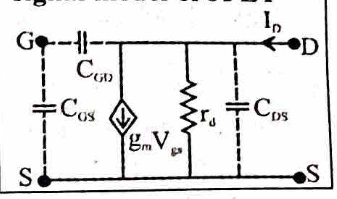
- ➢ Drain current $\boxed{I_D=K\left(V_{GS}-V_T\right)^2}$
- ➢ Amplification factor $\boxed{(\mu)=g_m\times r_d}$
- ➢ Transconductance g_m

$$\boxed{g_m=-2\frac{I_{DSS}}{V_P}\left[1-\frac{V_{GS}}{V_P}\right]} \text{ or } \boxed{g_m=\frac{2}{|V_P|}\cdot\sqrt{I_{DS}I_{DSS}}}$$

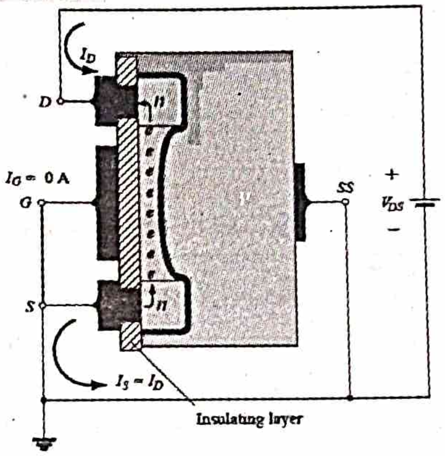
- ➢ $g_m=g_{mo}\left[1-\frac{V_{GS}}{V_P}\right]$ where $g_{mo}=\frac{-2I_{DSS}}{V_P}$

Or $g_m=\frac{2}{|V_P|}\sqrt{I_{DSS}\cdot I_D}$, $g_m=\left.\frac{\Delta I_D}{\Delta V_{GS}}\right\vert_{V_{DS}=\text{constant}}$

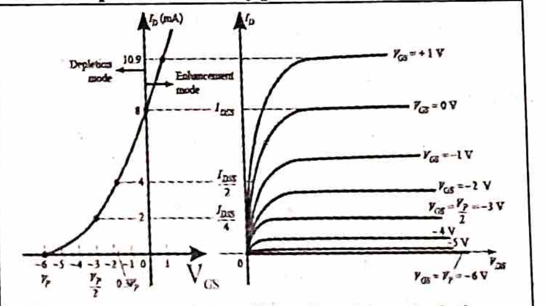
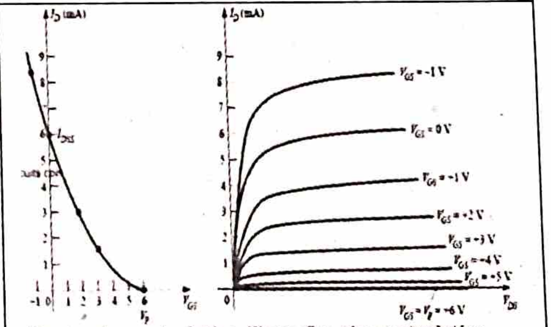
- ➢ Drain resistance $r_d=\frac{\Delta V_{DS}}{\Delta I_D}$
- ➢ $|V_{GS}|_{\text{off}}=|V_P|$

Low Frequency small signal model of JFET	High Frequency small signal model of JFET
	 G I_D D C_{GD} C_{GS} g_mV_{gs} r_d C_{DS} S S

❑ MOSFET



n-channel diplacement type MOSFET

n-channel MOSFET character-istics	 Drain characteristics Transfer characteristics
p-channel MOSFET character-istics	 Drain characteristics Transfer characteristics

- **For N-Channel MOSFET-**
- ➢ $V_{GS}\geq V_{Tn}$ (Cut – off region)
- ➢ $V_{DS}\leq\left(V_{GS}-V_{Tn}\right)$ (Triode region)
- ➢ $V_{DS}>\left(V_{GS}-V_{Tn}\right)$ (saturation region)
- ➢ Drain current in triode region

$$\boxed{I_D=\frac{\mu_n C_{ox}W}{L}\left[\left(V_{GS}-V_T\right)V_{DS}-\frac{1}{2}V_{DS}^2\right]}$$

(where, $\frac{\mu_n C_{ox}W}{L}=k_n$)

- ➢ Drain source current in saturation region

$$\boxed{I_{DS} = \frac{\mu_n C_{ox} w}{2L}(V_{GS} - V_T)^2}$$

Where, $\frac{\mu_n C_{ox} w}{2L} = k_n$

- **For P-Channel MOSFET-**
  - $V_{SG} \geq |V_{TP}|$ (Cut-off region)
  - $V_{SD} \leq V_{SG} - |V_{TP}|$ (Triode region)
  - $V_{SD} > V_{SG} - |V_{TP}|$ (Saturation region)
  - Drain resistance $r_d = \frac{r_0}{\left(1 - \frac{V_{GS}}{V_p}\right)^2}$

Remember point

- For a MOSFET operating in saturation region, channel length modulation effect causes decreases in output resistance.
- In triode region FET works as voltage variable resistor (VVR)
- For depletion MOSFET channel is diffused and current flows even if V_{GS} is zero.
- It operation in two mode depletion mode and enhancement mode for V_{GS} greater than threshold voltage it works in enhancement mode.

- **Comparison of different type of coupling-**

Type of coupling	Coupling device	Frequency response	cost	Impedance Matching	Use
RC Coupling	Capacitor	Excellent in audio frequency range	Less	Not good	Voltage Amplification
Transformer coupling	Transformer	Poor	More	Excellent	Power amplification and impedance matching
Direct coupling	No coupling Device used	Best at low frequency and dc	Least	Good	for low frequency Amplification

- **Difference Between Voltage and power Amplifier**

Parameter	Voltage Amplifier	Power Amplifier
β	High (> 100)	Low (5 to 20)
R_C	High (4-10 kΩ)	Low (5 to 20 Ω)
Coupling	Usually RC Coupling	Transformer Coupling
Input Voltage	Low (a few mV)	High (2-4V)
I_C	Low (≈ 1mA)	High (> 100mA)
Power output	Low	High
O/P impedance	High	Low

☐ Classification of power Amplifier

Class -A amplifier	• Transistor operates in active region at all time. • Unloaded voltage gain of CE amplifier, $A = -\frac{R_C}{r_e'}$ • Loaded voltage gain, $A_v = -\frac{r_C}{r_e'}$ • Maximum AC load power $P_{L(max)} = \frac{V_{PP}^2}{8R_L}$ • Stage efficiency $\eta = \frac{P_{L(max)}}{P_S} \times 100\%$ • Class A amplifier produces least distortion in the output among all power amplifiers.
Class-B amplifier	• Q Point is located at cut off on both DC and AC load line. • Collector-emitter voltage at Q-point $V_{CEQ} = \frac{V_{CC}}{2}$ • AC load power of a class B push-pull amplifier $P_L = \frac{V_{PP}^2}{8R_L}$ • Output signal is half sinusoidal. • Power drain is almost zero.
Class -AB amplifier	• Operating point is located between the limits of class AB • Collector current flow for more than half sinusoidal but not fully sinusoidal. • Distortion is more than Class-A but less than class-B. • Power drain is more than class-B but less than class-A
Class C-amplifier	• It is operated either is deep saturated or in deep cut-off region • Resonant frequency of tank circuit $f_r \simeq \frac{1}{2\pi\sqrt{LC}}$ • AC load power class- C amplifier $P_L = \frac{V_{PP}^2}{8R_L}$ • It has highest conversion efficiency among all power amplifiers. • Highest distortion. • It is used in tuned power amplifier and radio frequency amplifier.

- **Amplifier harmonics distortion**

$I_c = A_0 + A_1\cos\omega t + A_2\cos 2\omega t + \ldots\ldots A_n\cos n\omega t$

$\%D = \left|\frac{A_n}{A_1}\right| \times 100\%$ Where n=1,2,3……..as so on.

Total harmonic distortion %

$$D = \sqrt{D_2^2 + D_3^2 + D_4^2 + \ldots D_n}\ \%$$

Power Amplifier	**Conduction Angle**	**maximum Efficiency**	**Figure of merit**
Class-A	360°	50%(T/F), 25% (RC)	2
Class-B	180°	78.5%	0.4
Class-AB	180°-360°	50-78.5%	0.4-2
Class-C	< 180°	≥ 90%	< 0.25

☞ Remember point

- ➢ Cross over distortion occur- Class B amplifier.
- ➢ Cross over distortion reduced- Class AB amplifier.
- ➢ The harmonic distortion increases as we go from class A to C. So class A has minimum distortion.

❑ Feedback Amplifiers

- **Feedback-** The processes of injecting a fraction of output energy of same device back to its input is known as feedback.
- **Positive (Regenerative or Direct) feedback-**
  - ➢ Amplifier introduces 180° phase shift.
  - ➢ Feedback Network introduces 180° phase shift.

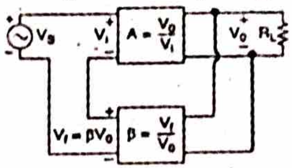
$$A_f = \frac{A}{1 - A\beta}$$

  - ➢ Use for oscillator
- **Negative (Degenerative or inverse) feedback**
  - ➢ Amplifier introduces 180° phase shift.
  - ➢ Feedback Network introduces 0° phase shift.

$$A_f = \frac{A}{1 + A\beta}$$

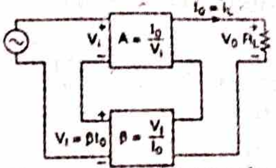
  - ➢ Use for amplifier
- **Return difference-**(de-sensitivity)
  - ➢ Difference between unity and loop gain is called return difference (D) - $\boxed{D = 1 + A\beta}$
- **Sensitivity**
  - ➢ In the case of negative feedback, if,
  - ➢ $\frac{\partial A}{A}$ - % Change without feedback.
  - ➢ $\frac{\partial A_f}{A_f}$ - % Change with feedback.
  - ➢ Reduction in sensitivity $\frac{\partial A_f}{A_f} = \frac{\partial A / A}{1 + A\beta}$

- **Voltage series topology**



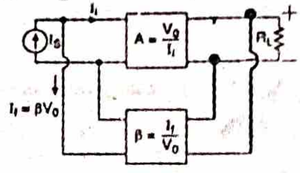
V_s
V_i
$A = \frac{V_o}{V_i}$
V_o
R_L
$V_f = \beta V_o$
$\beta = \frac{V_f}{V_o}$

- **Current series topology**



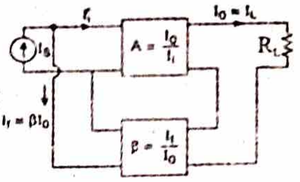
$I_o = I_L$
V_i
$A = \frac{I_o}{V_i}$
V_o
R_L
$V_f = \beta I_o$
$\beta = \frac{V_f}{I_o}$

- **Voltage shunt topology**



I_i
I_s
$A = \frac{V_o}{I_i}$
R_L
$I_f = \beta V_o$
$\beta = \frac{I_f}{V_o}$

- **Current shunt topology**

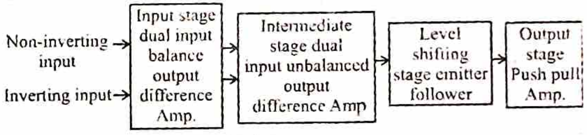


I_i
$I_o = I_L$
I_s
$A = \frac{I_o}{I_i}$
R_L
$I_f = \beta I_o$
$\beta = \frac{I_f}{I_o}$

Characteristics	**Types of feedback**			
	Voltage series	**Voltage shunt**	**Current series**	**Curren t shunt**
Voltage gain	Decrease	Decrease	Decrease	Decrease
Bandwidth	Increase	Increase	Increase	Increase
Harmonic Distortion or noise	Decrease	Decrease	Decrease	Decrease
Input Impedance	Increase	Decrease	Increase	Decrease
Output Impedance	Decrease	Decrease	Increase	Increase
Used	Common collector	Collector to base bias	Common emitter	Cascading amplifier

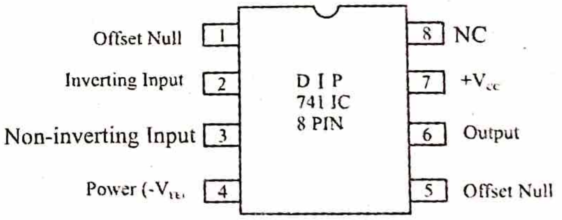
❑ Operational Amplifier-

- **Internal part :**



Non-inverting input
Inverting input
Input stage dual input balance output difference Amp.
Intermediate stage dual input unbalanced output difference Amp
Level shifting stage emitter follower
Output stage Push pull Amp.

- **History about OP - AMP-**
  - ➢ First patent for vacuum tube op-amp - 1946
  - ➢ First Commercial op-amp available - 1953
  - ➢ First discrete IC-op-amp- 1961 ➢ Op-amp 741 –1967
  - ➢ First Commercially successful monolithic op-amp-1965
  - ➢ Op-amp is a voltage controlled voltage source device.
- **Pin Diagram of 741 IC-**



Offset Null
1
Inverting Input
2
Non-inverting Input
3
Power (-V_{cc})
4
D I P
741 IC
8 PIN
8
NC
7
+V_{cc}
6
Output
5
Offset Null

Property	**Ideal op-amp**	**Practical op-amp**
Open loop gain (A_{OL})	∞	10^6
Input Resistance (R_i)	∞	1 MΩ
Output Resistance (R_0)	0	50 to 100 Ω
Bandwidth	∞	5MHz
Offset voltage	0	2 mV
Offset current	0	20 nA
CMRR	∞	10^6 or 120 dB
Slew rate	∞	80 V/μ sec
Voltage Gain	∞	2×10^5

- **Input Bias Current-** $\boxed{I_{bias} = \frac{i_1 + i_2}{2}}$

➢ Its value between 80nA to 500nA.

- **Input offset current-** $\boxed{i_{oc} = i_1 \sim i_2}$

➢ Its value between 20nA to 200nA.

- **CMRR (Common Mode Rejection ratio)-**

➢ $\boxed{V_{ocm} = A_{cm}V_{cm}}$

V_{cm} - Common mode input, A_{cm} - Common mode Gain

V_{ocm} - output of common mode configuration.

$\boxed{V_0 = A_{OL}V_d + A_{cm}V_{cm}}$

- $\boxed{CMRR = \frac{A_{dm}}{A_{cm}}}$ • $\boxed{CMRR = 20\log_{10}\frac{A_{dm}}{A_{cm}}\ dB}$

➢ CMRR is high - rejection of noise high.

➢ When emitter resistance R_E ↑ then CMRR ↑

A_{dm} = difference mode gain

A_{cm} = common mode gain

$$A_{cm} = \frac{V_{out}}{V_{in(cm)}} = \frac{-R_C}{r_e + 2R_E} = \frac{-R_C}{2R_E}$$

- **Slew Rate-**

- $\boxed{SR \ge \left.\frac{dv}{dt}\right|_{max}}$ • $\boxed{SR \ge \frac{A_{CL}V_m\omega}{10^6}, \frac{V}{\mu sec}}$ • $\boxed{SR \ge 2\pi FV_m, \frac{V}{S}}$

Where, V_m = Peak value of sinusoidal input or output

$\omega = 2\pi f$ =input signal of frequency.

➢ Slew rate depends on input signal frequency and output amplitude.

- **Golden rule about op-amp-**

➢ Op-amp mostly ideal op-amp ($A_{OL} = \infty$, $R_i = \infty$)

➢ Virtual ground and virtual short Applicable only- ideal op-amp, with Negative feedback.

➢ Virtual Ground and virtual short not applicable only- Positive feedback, Open loop case, Practical op-amp.

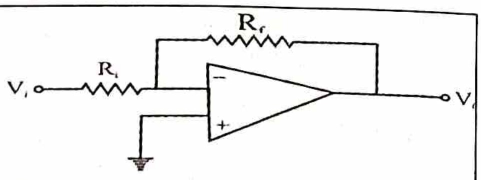
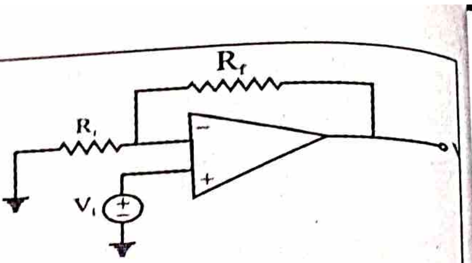
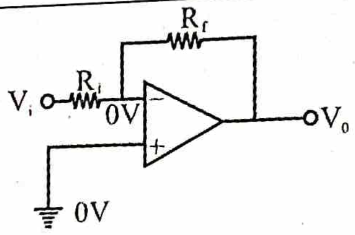
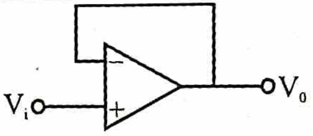
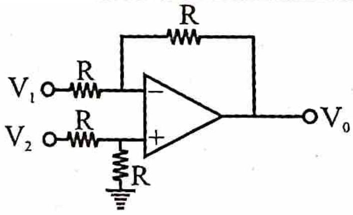
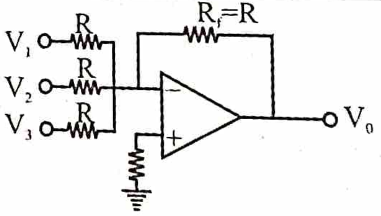
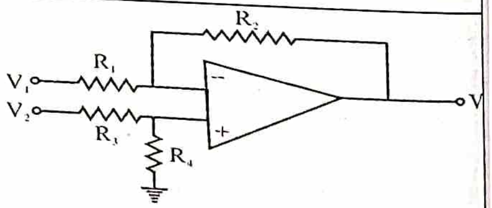
- **Power supply rejection ratio (PSRR)**

$\boxed{PSRR = \frac{\Delta V_{io}}{\Delta V}, \frac{\mu V}{V} \text{or dB}}$

ΔV_{io} = Change in input offset voltage

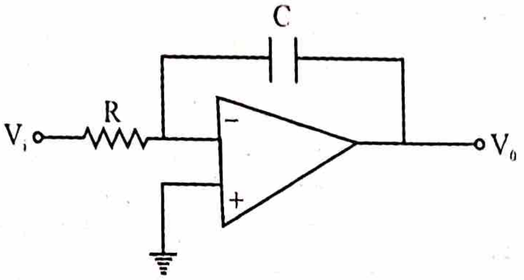
ΔV = Change in supply voltage.

- **Linear op-amp Circuits-**

Inverting Amplifier	 $\boxed{A_V = -\frac{R_f}{R_i}}$
Non-inverting Amplifier	 $\boxed{A_v = 1 + \frac{R_f}{R_i}}$
Phase shifter	 R_f V_i R_i 0V V₀ - + 0V $\frac{V_0}{V_i} = \frac{-R_i}{R_f}$
Voltage follower	 $V_0 = V_i$
Substractor	 R V₁ R V₂ R V₀ R - + $V_0 = V_2 - V_1$
Inverter adder	 R_f=R V₁ R V₂ R V₃ R V₀ - + $V_0 = -(V_1 + V_2 + V_3)$
Difference Amplifier	 R₂ R₁ V₁ V₂ R₃ R₄ V - + $\boxed{V_0 = -\frac{R_2}{R_1}V_1 + \left(\frac{R_4}{R_3+R_4}\right)\left(1+\frac{R_2}{R_1}\right)V_2}$ if $\frac{R_2}{R_1} = \frac{R_4}{R_3}$ then, $\boxed{V_0 = \frac{R_4}{R_3}[V_2 - V_1] = \frac{R_2}{R_1}(V_2 - V_1)}$

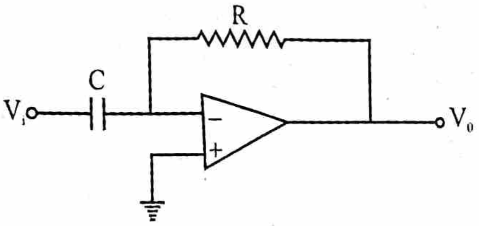
❑ Non-linear op-Amp circuits-

- **Integrator**



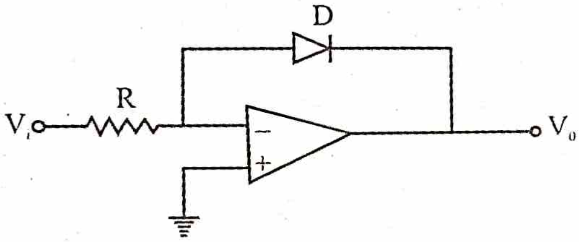
$$\boxed{V_0 = -\frac{1}{RC}\int V_i dt + V_C(0^+)}$$

- Also known as low pass filter.
- **Differentiator**



$$\boxed{V_0 = -RC\frac{dV_i}{dt}}$$

- Also known as high pass filter.
- **Logarithmic Amplifier**



$$\boxed{V_0 = -\eta V_T \ell n\frac{V_i}{I_0 R}}$$

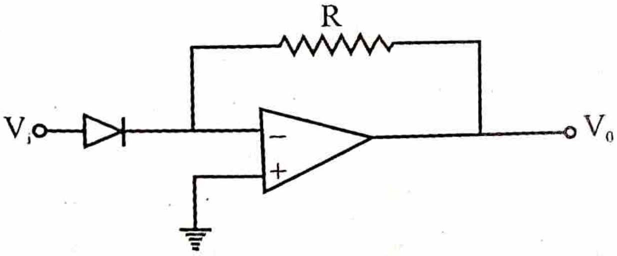
Where,

η = Recombination factor

V_T = Thermal voltage

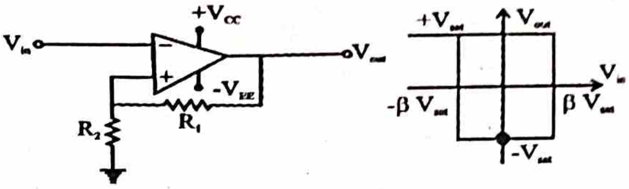
I_0 = Reverse saturation current of diode.

- **Antilog Amplifier**



$$\boxed{V_0 = -I_0 R \text{ anti} \log\frac{V_i}{\eta V_T}}$$

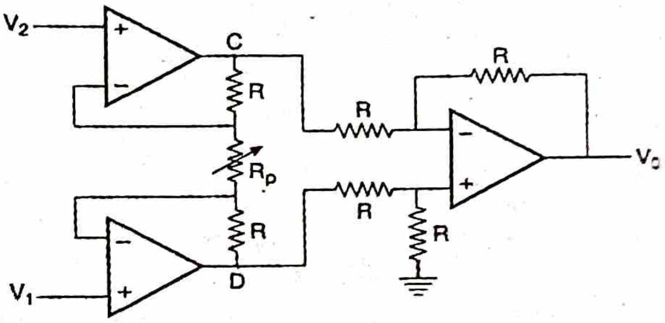
- **Schmitt trigger –**


$+V_{CC}$
V_{in}
V_{out}
$-V_{EE}$
R_1
R_2
$+V_{sat}$
V_{out}
V_{in}
$-\beta V_{sat}$
βV_{sat}
$-V_{sat}$

$$\boxed{V_{TH} = \beta V_{sat} = \left(\frac{R_2}{R_1+R_2}\right)V_{sat}} \quad \boxed{V_{HTL} = V_{TH} - V_{TL}}$$

$$\boxed{V_{TL} = -\beta V_{sat} = \left(-\frac{R_2}{R_2+R_1}\right)V_{sat}}$$

- **Instrumentation Amplifier**

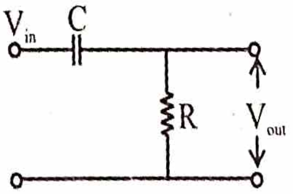

V_2
V_1
C
D
R
R_P
R
R
R
R
R
V_0
+
–
–
+
–
+

➢ $\boxed{V_0 = \left(\frac{1+2R}{R_P}\right)(V_1 - V_2)}$ $\boxed{\text{Current in } R_p, I = \frac{V_2 - V_1}{R_p}}$

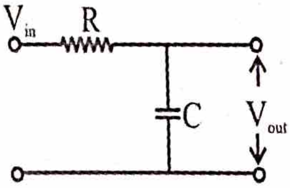
➢ Point C voltage $\boxed{V_2 + \frac{V_2 - V_1}{R_p}R}$

➢ Point D-voltage $\boxed{V_1 - \frac{V_2 - V_1}{R_p}R}$

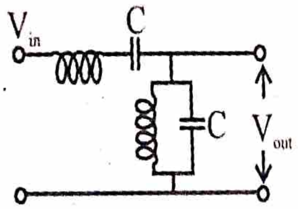
- High pass filter



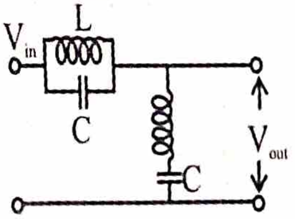
- Low pass filter



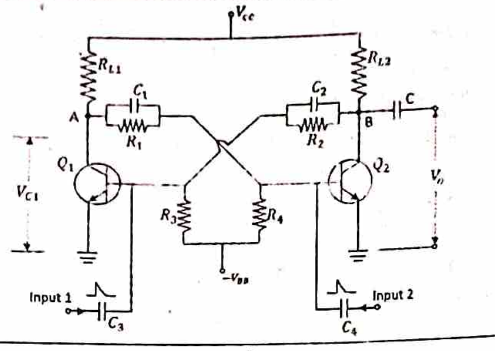
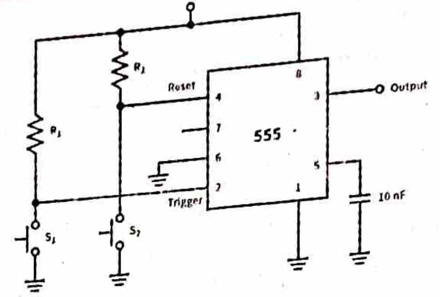
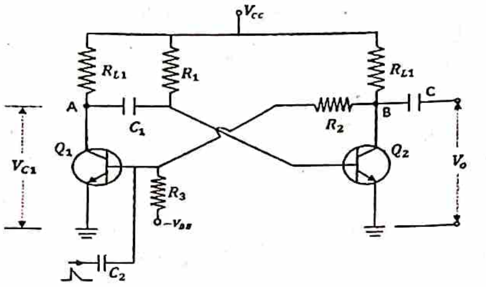
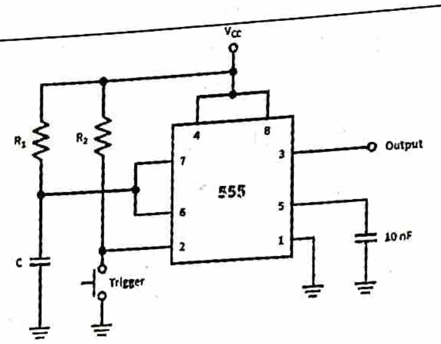
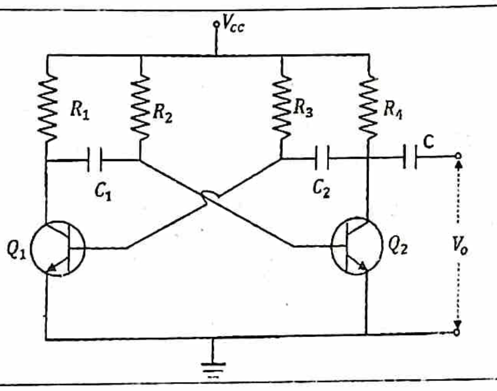
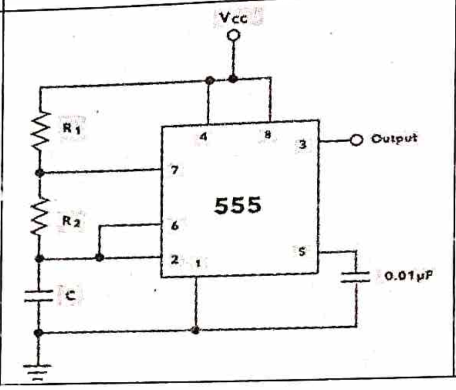
- Band pass filter



- Band reject filter


V_{in}
L
C
C
V_{out}

❑ Multivibrators

Multivibrators	Circuit diagram	Multivibrators by using IC 555	Application
Bistable			Flip-Flop, Memory, Mathematical operation etc.
Monostable			Pulse generator, delay circuit, gating circuit etc.
Astable			Oscillator, Timing Circuit, Square wave Generation, PWM, linear ramp generator, frequency divider etc.

- **Differentiator**

Input	Output
Square wave / Rectangular wave	Spikes, impulse
Triangular wave	Square wave
Sine wave	Inverted cosine
DC	Zero
$\boxed{RC <<< T_P}$	RC-Time constant, T_P - Propagation delay

- **Integrator**

Input	Output
Spikes or impulse	Square or rectangular
Square wave	Triangular wave
Sine wave	Cosine wave
DC or Step	Ramp
Rectangular	Sawtooth wave
$\boxed{RC >>> T_P}$	

- **Fixed Voltage IC Regulators-**

i. **78XX-** It provide fixed output positive voltage
$7805 \to V_0 = +5V, 7812 \to V_0 = +12V$

ii. **79XX** - It provide fixed Negative DC voltage.
$7905 \to V_0 = -5V, 7912 \to V_0 = -12V$

➢ For proper operation of IC voltage at input PIN should be atleast 2V higher than the voltage at output.

- **IC 555 Timer**

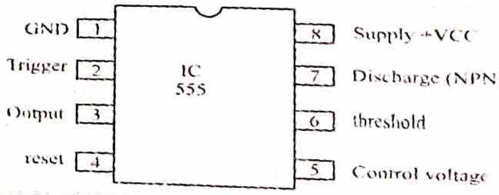
➢ It is used in Tone, and Alarm Generation.

➢ It is used in Generation of square wave, sawtooth wave.

➢ It is available in 8-pin DIP package.

➢ It is made up Bipolar technology and CMOS technology.

- **PIN Diagram-**



- **IC 555 as Astable multivibrator**

➢ $\boxed{T_{charge} = (R_A + R_B)C}$ ➢ $\boxed{T_{discharge} = R_B C}$

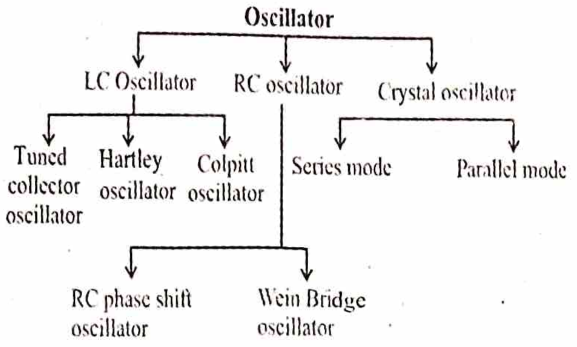
➢ $\boxed{T_{High} = 0.69(R_A + R_B)C}$ ➢ $\boxed{T_{Low} = 0.69 R_B C}$

- ➢ $\boxed{T_0 = T_{High} + T_{Low}}$ ➢ $\boxed{T_0 = 0.69(R_A + 2R_B)\,C}$
- ➢ $\boxed{f_0 = \frac{1}{T_0} = \frac{1.45}{(R_A + 2R_B)C}}$

- **IC 555 as monostable multivibrater**

- ➢ $T_{charge} = RC,\ \ T_{discharge} \cong 0$ $\boxed{T_0 = 1.1T_{charge}}$
- ➢ Also used in frequency division
- ➢ Used in relay switching, ➢ Generation time delay

☐ Oscillator

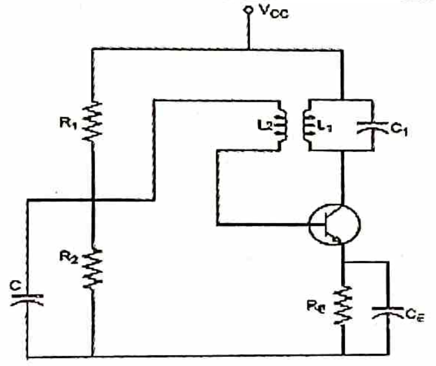
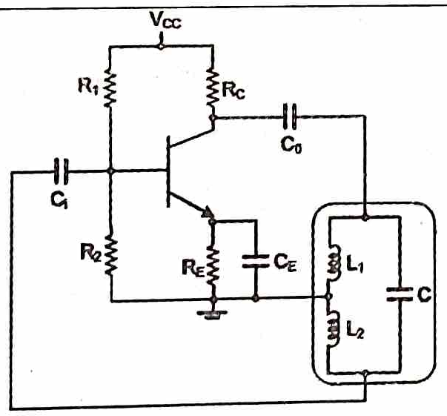
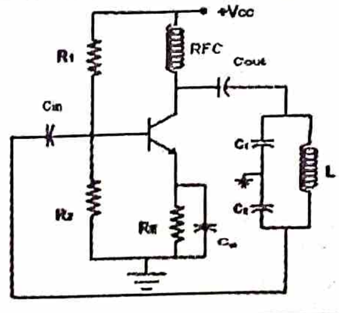

Oscillator
LC Oscillator
RC oscillator
Crystal oscillator
Tuned collector oscillator
Hartley oscillator
Colpitt oscillator
Series mode
Parallel mode
RC phase shift oscillator
Wein Bridge oscillator

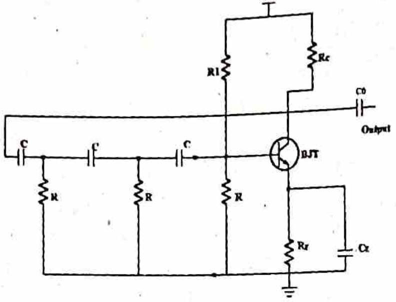
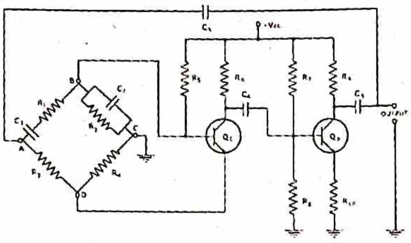
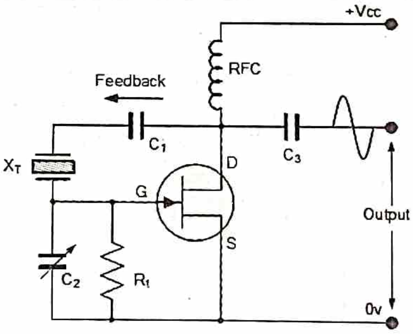
Type of component	Frequency of Oscillation	Waveform generation
RC Oscillator	Audio frequency	Sinusoidal
LC Oscillator	Radio frequency	Square wave
Crystal Oscillator	Radio frequency	Triangular wave, Sawtooth wave etc.

- ➢ Audio frequency oscillator - up to 20 kHz
- ➢ Radio frequency oscillator - 20 kHz to 30MHz
- ➢ Very High frequency - 30 MHz to 300MHz
- ➢ Ultra High frequency oscillator - 300 MHz to 3 GHz
- ➢ Microwave frequency oscillator - 3 GHz to thousand GHz

- **Barkhausen's Criteria for Oscillation-**

1. Positive feedback 2. $A\beta = 1$ or $\beta = \frac{1}{A}$
3. The loop gain must be unity or greater.
4. The feedback signal feeding back at the input must be phase - shifted by 360° . In most of the circuits inverting amplifier is used to produce 180° phase shift and additional 180° phase shift is provided by the feedback network.

Type of oscillator	Diagram	Frequency	Application
Tuned Collector Oscillator	 Vcc R₁ L₂ L₁ C₁ R₂ C R_E C_E	$\boxed{f = \frac{1}{2\pi\sqrt{L_1C_1}}}$	RF oscillator circuits, mixers, frequency demodulators, signal generators
Hartley Oscillator	 Vcc R₁ Rc C₀ C₁ R₂ R_E C_E L₁ L₂ C	$\boxed{f = \frac{1}{2\pi\sqrt{(L_1 + L_2 + 2M)C}}}$	• As a local oscillator in radio receivers. • Suitable for oscillations in radio frequency (RF) range up to 30 MHz • Used for producing since wave with the desired frequency.
Colpitt Oscillator	 +Vcc R₁ RFC Cout Cin C₁ L C₂ R₂ R_E C_E	$\boxed{f = \frac{1}{2\pi\sqrt{\left(\frac{C_1C_2}{C_1 + C_2}\right) \times L}}}$	• Generation of sinusoidal output signal with very high frequency • As a temperature sensor, RF oscillator, local oscillator (radio receiver) • Mobile application

RC Phase Shift Oscillator	 Vcc Rc R1 C0 Output C C C BJT R R R Rr Cr	$\boxed{f = \frac{1}{2\pi RC\sqrt{6}} Hz}$ $\boxed{\beta = -\frac{1}{29}\text{(Feedback Factor)}}$	- Musical instruments, GPS unit and voice synthesis. - Generation of signal over a wide range of frequencies - Capable of working at all audio frequencies.
Wein Bridge Oscillator	 C +Vcc A B C D C1 R1 Q1 Q2 OUTPUT	$\boxed{f_0 = \frac{1}{2\pi\sqrt{R_1C_1R_2C_2}}}$ then $\boxed{f = \frac{1}{2\pi RC}}$ When $R_1 = R_2 = R$ and $C_1 = C_2 = C$ $\beta = \frac{1}{3}$ for oscillation $R_2 \geq 2R_1$ For oscillation	- Precision measurement of capacitance in terms of resistance and frequency. - Generate audio and sub-audio frequencies ranging between 20 Hz to 20 kHz - Harmonic distortion analyzer and HF oscillator.
Crystal Oscillator	 +Vcc RFC Feedback C1 C3 XT D G S Output C2 R1 0v	$\boxed{f_s = \frac{1}{2\pi\sqrt{LC}}}$ $\boxed{f_p = \frac{1}{2\pi\sqrt{LC_{eq}}}}$	- Best frequency stability - Used in computers, instrumentation, digital system, in phase locked loop system, modems, marine, telecommunications, sensors, disk drives, stereo, GPS system and automobile applications

☞ Remember point

➢ Quartz has excellent physical characteristics which do not get affected by time and temperature, hence crystal oscillator provides highly stable f_0.

➢ Relaxation oscillator and UJT oscillator are non-linear oscillator.

- **Clipper and clamper comparison chart**

Parameters	**Clipper**	**Clamper**
Definition	Clipper removes the amplitude of the output voltage	Clamper shifts the DC level of the output voltage
Output voltage	Less than the input voltage	Multiples of input voltage
Energy storage component	Not required	Requires (capacitor is used as energy storage element)
Shape of output waveform	Shape changes (rectangular, sinusoidal, triangular etc)	Shape remains same as input waveform.
DC level	Remain same	DC level get shifted
Applications	In transmitters, receivers, amplitude selector, noise limiter etc.	In voltage multiplying circuits, Sonar, Radio system.

☞ Remember point

➢ BJT has high sensitivity in both BJT and FET at same input.

➢ BJT-BJT → A_1 (Gain); FET-BJT → A_2 (Gain) FET-FET → A_3 (Gain) ; then $A_1 > A_2 > A_3$

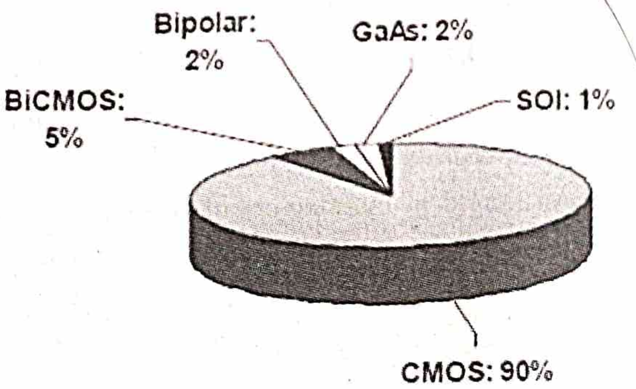
Advance Electronics

❑ Introduction VLSI Fabrication Technologies :

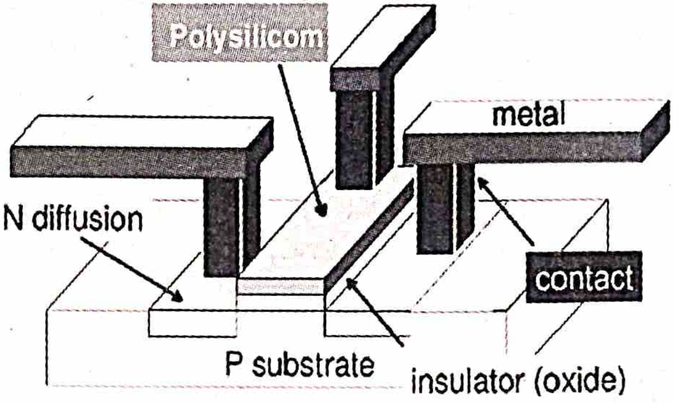
■ Main categories of Materials

- ➢ Materials can be classified into three main groups regarding their electrical conduction properties:
- ➢ Insulators ➢ Conductors ➢ Semiconductors
- ➢ Conductors are used in IC design for electrical conductivity. The following are good conducting elements:
- ➢ Silver ➢ Gold ➢Copper
- ➢ Aluminum ➢ Platinum
- **Semiconductors:**
- ➢ The basic semiconductor material used in device fabrication is **silicon**
- **The success of this material is due to:**
- ➢ Physical characteristics
- ➢ Abundance in nature and very low cost
- ➢ Relatively easy process
- ➢ Reliable high volume fabrication
- ➢ Other semiconductors (e.g. GaAs) are used for special applications
- **Organization:**
- ➢ Materials Used in VLSI Fabrication
- ➢ VLSI Fabrication Technologies
- ➢ Overview of Fabrication Methods
- ➢ Device simulation
- **Overview of Processing Technologies:**

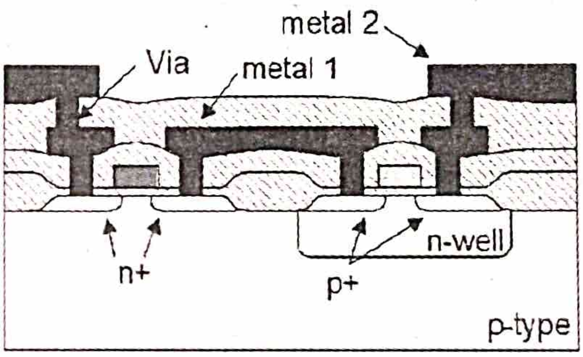
Although a number of processing technologies are available, the majority of the production is done with traditional CMOS. Other processes are limited to areas where CMOS is not very suitable (like high speed RF applications)



■ Simplified View of MOSFET :



- **CMOS Process:** The CMOS process allows fabrication of nMOS and pMOS transistors side-by-side on the same silicon substrate.



- **Different types of IC technologies are-**

Monolithic Technology	• "Epitaxial Technology" • This fabrication for active components. Resistor in an exception which is a passive component but is formed by monolithic technology.
Thin film Technology	Used for fabrication of passive components. In this the thickness of silicon wafer of 50 Å to 50, 000 Å .
Thick film Technology	• Used for fabrication of passive components. In this the thickness of silicon wafer of 1,25000 Å – 6,25,000 Å • Almost all the entire IC is fabricated on a single crystal of silicon.

- **Advantages of IC Fabrication-**

Advantages	• Cost reduction due to bulk manufacturing. • Smaller in size, can be easily portable. • High reliability with minimum electrical and mechanical failure because no soldering is used for the inter-connection of components. • Improved performance compared to the discrete circuit components. • Matched device.
Disadvantages	• Very sensitive to voltage fluctuations, high temperature & humidity

- **Fabrication process :**

The following steps are involved in the process of IC's fabrication.

- ➢ Preparation of silicon water.
- ➢ Epitaxial deposition.
- ➢ oxidation
- ➢ Photolithography and chemical etching.
- ➢ Diffusion.
- ➢ Ion-Implantation
- ➢ Metallization
- ➢ Circuit testing - It is not a direct part of the IC fabrication.

■ Water cleaning :

- ➢ First step in the IC fabrication.
- ➢ Zone refining is used to make the silicon water with ultra pure (99.99% purity) and polycrystalline Si is obtained.
- ➢ Zone refining is done by using RF Induction current meter.
- ➢ Czochralski Method is used to provide poly crystallization one the silicon water.
- ➢ Typical value of silicon water is 0.5μm and resistivity of the silicon water is 10Ω-cm.

■ Mask Making :

- ➢ Circuit layout is prepared by the manufacture, depending on the original circuit and a negative film or an x-ray is taken for the layout and it is called mask.
- ➢ The area where components are to be made is darkened and the x-ray film is pasted to the Si-water.

■ Photo Lithography: Means "Photo Engraving"

- ➢ Photo-lithography refers the process of transforming the pattern (layout) on the working mask onto the silicon wafer.
- ➢ Silicon wafer is now coated with a photoresist and the entire. wafer will be exposed to ultra violet light.

■ Photoresists :

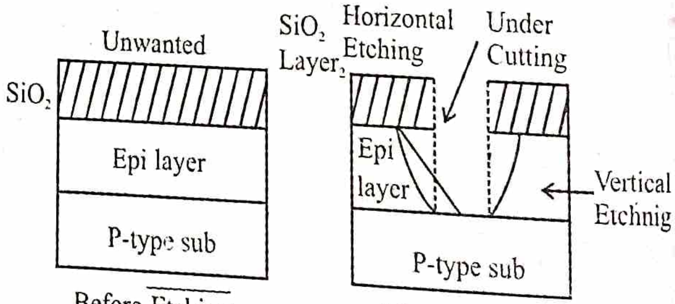
- **Photoresists are of two types :**

Positive Resist	When exposed to the UV light, positive resist becomes more soluble to the developing chemicals.
Negative Resist	When exposed to the UV light, negative resist will be come less soluble to the developing chemical.

- ➢ Positive resist is more popular than negative resist because of higher resolution.
- ➢ Exposed area of the resist are removed, leaving the unexposed portions intact.

■ Etching : Wet Etching - "Isotropic Etching"

- ➢ Defined as the removal of material from unwanted areas.
- ➢ Wet Etching done by using Hydrofloric acid (HF).
- ➢ Perfect etching is not possible by using the wet etching.
- ➢ Disadvantage of wet etching is under cutting.
- ➢ Generally used when the chip size are greater than 2μm.



Before Etching

After etching

- ➢ In the wet etching, lateral etching is mode almost equal to vertical etching.
- ➢ Dry etching-done by using one of the inert gases.
- ➢ Dry etching is also called "ant isotropic etching".
- ➢ In dry etching, there is no undercutting.
- ➢ Dry etching used where the chip size is less than 2μm.

Epitaxial Growth :

- Epitaxial means creating a very thin layer of μm thickness of the substrate material and the layer is called as "Epi-Layers"
- Epitaxial can be further classified into Vapor Phase Epitaxy (VPE), Liquid phase Epitaxy (LPF) and Molecular Beam Epitaxy (MBE).

Oxidation :

- It is the process by which SiO_2 is deposited on the Si-wafer.
- SiO_2 is a insulator, and it will protect the silicon surface against unwanted contaminations called "passivation".

Advantages of passivation :

- Provides very leakage current between the junction
- Done by using Hydrofluoric acid i.e. using wet etching.
- Protect silicon wafer surface by unwanted contamination.

Diffusion and Ion Implantation :

- Refers to introduction of impurities into the epitaxial layer through the etched window of SiO_2 for the formation of junction such as emitter base junctions and collector base junctions in BJT and to provide source and drain regions in the MOS transistor.
- Diffusion profile is given by:

$$N(x,t) = N_0 \operatorname{erf}\left(\frac{x}{2\sqrt{Dt}}\right) + N_B$$

Where,

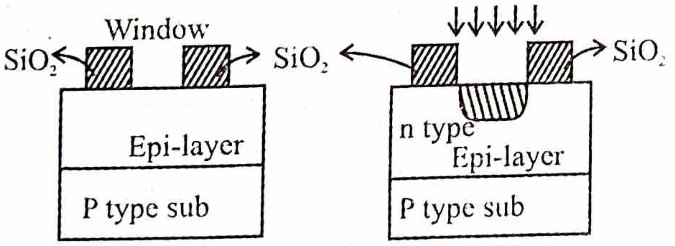
N_0 = Solid solubility of the dopant in the Semiconductor

N_B = Original doping concentration.

D = Diffusion coefficient.

t = Diffusion time,

x = distance from the sample surface.



Before Diffusion

After Diffusion

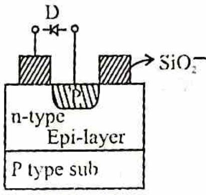
- Ion Implantation is also used to reduce the threshold voltage of the MOSFET.
- Ion Implantation is alternate method of diffusion and it is the most common method and is usually done at low temperature.

Advantage of Ion Implantation :

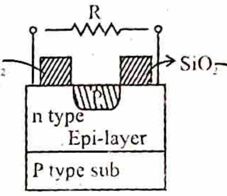
- Precise doping of the window between SiO_2 is possible.
- It is done at low temperature and reduce threshold voltage (V_{th}) of MOSFET
- **SiO_2 Role in IC Fabrication:**
- As on isolation layer between the junction
- As a passivation layer
- As a dielectric between the poly silicon gate and semiconductor channel.
- As an Isolation material between the devices.
- **Metallization:**
- Process of Inter connection of components for final functioning of the designed circuits.
- Metallization is done by sputtering. In the sputtering techniques, hair like structures of gold is used for the inter-connection of components.

Testing and Packaging :

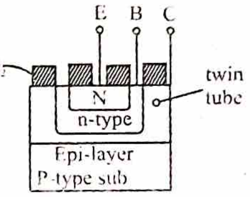
- After completing all the steps in the IC fabrication, the IC is made and it is tested for its working and is also used to test for quality control.
- The tested IC is subjected to a package such as to package (metallic package) or DIP (dual in line package).



Fabricate a SC



Fabricate a R



Fabricate a PNP

Note:

- During IC fabrication in the monolithic the p-type substrate is generally connected to the most negative potential in the circuit.
- In epitaxial Method, fabricated on a single crystal of silicon.
- In planar Technology, device in IC fabrication are fabricated will take place through a single plan.
- While diffusion an Impurity into silicon, If the concentration of the Impurity atoms is maintained constant at the surface of the water then the diffusion impurity profile is caused complementary error function.

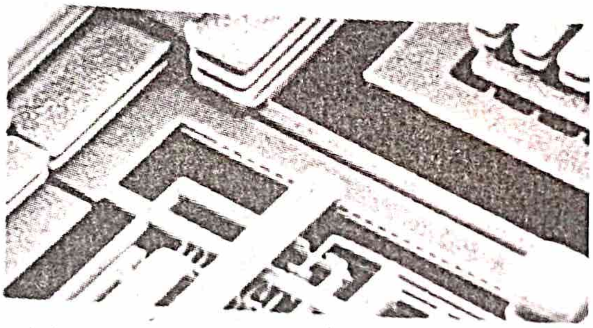
Annealing :

Thermal annealing is a high temperature process which:

- Allows doping impurities to diffuse further into the bulk
- Repairs lattice damage caused by the collisions with doping ions

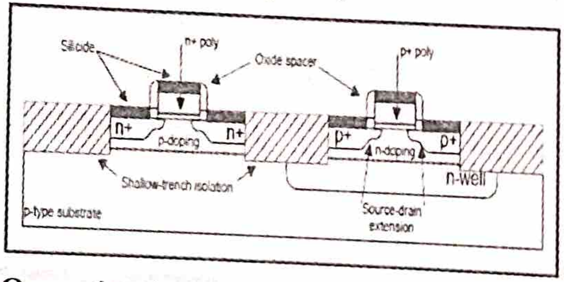
Silicon Deposition and Metallization

- Films of silicon can be added on the surface of a wafer
- **Epitaxy:** growth of a single-crystal semiconductor film on a crystalline substrate
- **Polysilicon:** Polycrystalline film with a granular structure obtained through deposition of silicon on an amorphous material
- **Metallization:** deposition of metal layers by evaporation
- interconnections



Advanced CMOS processes:

- Shallow trench isolation
- Source-drain halos (series resistance)
- Self-aligned silicide (spacers)



Organization :

- Materials used in VLSI Fabrication
- VLSI Fabrication Technologies
- Overview of Fabrication Methods
- Device simulation

MOS device simulation :

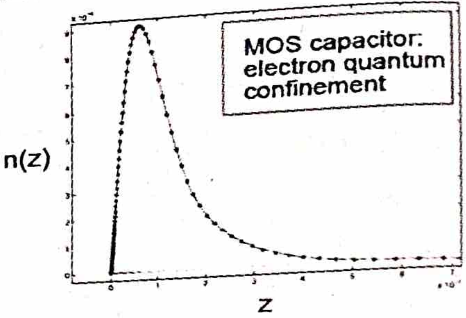
- 2D 0.18 μm n-channel MOS, tox = 4nm
- 8 refinement cycles
- I_d (V_{ds}) simulation, V_{gs} = 1.3V
- 8 refinement cycles
- Refinement on ψ, n, p

Research activities :

- Sophisticated 2D geometries (2nd generation wavelets)
- 3D geometries

Simulation issues :

- Advanced models (hydrodynamic, quantum effects)



VLSI Design :

- VLSI design is a sequential process of generating the physical layout of an IC, starting from the specification of that circuit.
- VLSI design use the software is called Electronic Design Automation (DEA) or Computer Aided Design (CAD).
- The Process of developing a chip from concept to silicon is divided into the following four tasks.

Design	It often starts with working research and product definition & is followed by system design.
Verification	It is means of ensuring that the chip can perform faithfully in functionality, according to its design specifications.
Implementation	It is the process of actually creating the hardware, which results in an entity that on can see & feel.
Software development	It is the process of programming the brain of the chip or arming the chip with intelligence.

Pipelining :

- It is to arrange the hardware so that more than one operation can be performed at the same time.
- Pipelining is a particularly effective way of organizing concurrent activity in computer system.
- They are two types of operation.

Instruction Pipeline	An instruction pipeline consists of multiple sections each of which perform one of the function of the instruction cycle for all the instructions.
Arithmetic Pipeline	• An arithmetic pipeline is similar to an assembly line in a factory. • It is used for floating point operations, multiplication and various other computations.

DIGITAL ELECTRONICS

☐ Number Systems and Codes

■ Advantages of Digital Techniques

- ➢ Size and cost is less.
- ➢ Accuracy and precision is greater.
- ➢ Information storage is easy.
- ➢ Power dissipation is less.

■ Signed Magnitude :

- ➢ For +ve number, write magnitude and append MSB to 0.
- ➢ For –ve number, write magnitude and append MSB to 1.

■ 1's Complement :

- ➢ For +ve number, write magnitude and append MSB to 0.
- ➢ For –ve number, write +ve number and then take it's 1's complement.

■ 2's Complement :

- ➢ For +ve number, write magnitude and append MSB to 0.
- ➢ For –ve number, write +ve number and then take it's 2's complement

■ (r – 1)'s Complement :

- ➢ Subtract the given number from maximum possible number in the given place.

■ r's Complement :

- ➢ Determine the (r – 1)'s complement then add 1 to the right most bit of (r – 1)'s complement.

■ Signed Binary Representation

Representation	Range
Unsigned magnitude	0 to 2^n-1
Signed magnitude	$-\left(2^{n-1}-1\right)$ to $+\left(2^{n-1}-1\right)$
Signed 1's representation	$-\left(2^{n-1}-1\right)$ to $+\left(2^{n-1}-1\right)$
Signed 2's representation	$-\left(2^{n-1}\right)$ to $+\left(2^{n-1}-1\right)$

- ➢ Main disadvantage of signed 1's complement, 0's has two representation "–0 to +0" while signed 2's complement, 0's have one representation "+0"

■ Weighted Code

- ➢ It is a positional weighted system.
  Ex Binary, octal, hexadecimal, BCD, 8421 etc.

■ Unweighted Code

- ➢ It is non-positional weighted system
  Ex. Gray code, Excess-3 code etc.

■ Codes

- ➢ Special grouped representation of numbers, letters or symbols.
- ➢ For n bit, Total number of different code = 2^n

- **There are three types of code-**

Non-Binary Codes	Represented in series of dots & dashes Eg. MORSE Codes.
Binary Codes	BCD, Excess-3, Gray Code, 8421 code, Error detecting & correcting code.
Alphanumeric Codes	ASCII-Code (07 bits + 01 parity bit) EBCDIC-Code (08 bits).

■ Binary Coded Decimal Code (BCD)

- ➢ Weighted Code
- ➢ It is also called 8421 code.
- ➢ Each individual bit of decimal no. is directly represented by its binary equivalent in the group of 04- bits.
- ➢ (BCD+0011) = Excess-3 code
- ➢ BCD code means that the decimal number 0 to 9 can be written from the code

■ BCD Addition

- ➢ **Case (I) :** sum ≤ 9 with carry zero→ no correction
- ➢ **Case (II) :** sum ≤ 9 with carry one → valid BCD number but incorrect result (invalid BCD result) to get correct BCD result correction factor of (0110) added in LSB
- ➢ **Case (III) :** Sum >9, with carry zero (0) → invalid BCD number to get valid BCD number add (0110)

■ Excess-3 Code

- ➢ Unweighted Code.
- ➢ It is a 4-bit code.
- ➢ This code is derived from BCD Code by adding "3" to individual bits of Coded number.
- ➢ It is a "Self Complementing (reflective)" Code.

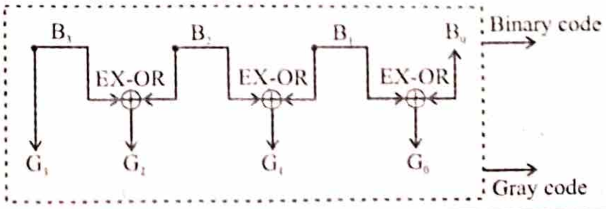
■ Excess-3 Addition

- ➢ **Case (I) :** If any group produces decimal carry, add (0011) to that group
- ➢ **Case (II):** If any group does not produces decimal carry subtract (0011) to that group.

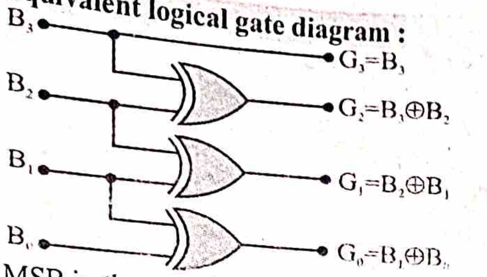
■ Gray Code

- ➢ Unweighted Code ➢ Reflected Code/cyclic code
- ➢ Minimum changing code, because there is single bit change in consecutive step change.

■ Binary to Gray Code Conversion

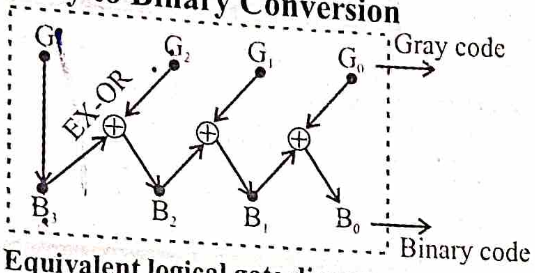


- **Equivalent logical gate diagram :**

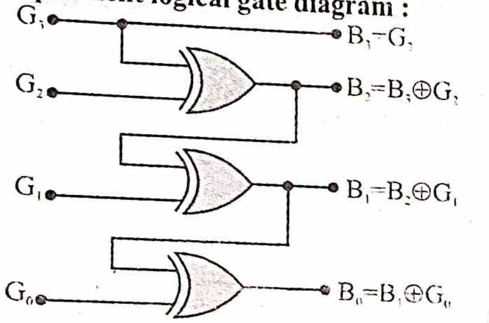


- ➢ MSB in the gray code is same as corresponding digit in binary number.
- ➢ Starting from 'Left to Right' add every attached pair of binary digits to get next and gray code digit.

Gray to Binary Conversion



- **Equivalent logical gate diagram :**



- ➢ MSB of the binary is same as that of gray code.
- ➢ Add each binary digit to the generated gray digit in the next attached location.

Number system	Base	Distinct symbols
Decimal number	10	0,1,2,3,4,5,6,7,8 &9
Binary number	2	0,1
Octal number	8	0,1,2,3,4,5,6 & 7
Hexadecimal Number	16 or H	0,1,.........9, A,B,C,D,E &F

Conversion of Number System :

- **Decimal Number System to other number system conversion.**
- **Decimal to Binary :**

➢ To convert a decimal number into an equivalent binary number we have to divide the original number system by 2 until the quotient is 0, when no division is possible. The remainder so obtained is counted for the required in the order of LSB to MSB.

- **Decimal to Octal :**

➢ To convert a decimal number into an equivalent octal number we have the divide the original number system by 8 until the quotient is 0. When no division is possible. The remainder so obtained is counted for the required in the order of LSB to MSB.

- **Decimal to Hexadecimal :**

➢ The given decimal number here is divided by 16 to get the equivalent hexadecimal. The division of the number continues until we get the quotient 0. Then, in the same way, we count the remainder from LSB to MSB.

Other number system to decimal number system conversion:

- **Binary to Decimal:**

➢ In this conversion, a number with base 2 in converted into number with base 10. Each binary digit here is multiplied by decreasing power of 2.

- **Octal to Decimal:**

➢ In this conversion, a number with base 8 is converted into number with base 10. Each digit of octal number here is multiplied by decreasing power of 8.

- **Hexadecimal to Decimal :**

➢ In this conversion, a number with base 16 is converted into number with base 10. Each digit of hex number here is multiplied by decreasing power of 16.

Steps for Fraction Part :

1. The given decimal fraction is successively multiplied by the base of the target number.
2. During each multiplication iteration, the product generated will have a carry (integer part of product) and fractional part.
3. The carry obtained at each multiplication step becomes a numeral in the new base system.
4. The fraction part is again multiplied by the new base number and process is repeated until the fractional part becomes zero or the number of multiplication iteration equals the number of digits
5. Weights are assigned for the carry obtained at each step such that carry obtained from 1st multiplication is most significant digit after the decimal point and last carry is least significant digit.

Hexadecimal to Binary :

➢ Each digit is represented with 4 bit binary equivalent.

Octal to Hexadecimal :

(i) First convert octal to binary and then binary to hexadecimal.

(ii) From hexadecimal to octal conversion first convert hexadecimal to binary and then binary to octal number.

Octal to Binary:

➢ Each digit is represented with 3 bit binary equivalent.

☐ Boolean Algebra

Commutative Law	• A+B = B+A • A.B = B.A
Associative Law	• A+(B+C) = (A+B)+C • A.(B.C) = (A.B)C = ABC
Distributive Law	• A(B+C) = AB + AC • A+(B.C) = (A+B).(A+C) • (A+B)(C+D) =AC+AD+BC+BD • $A+(\bar{A}.B)=A+B$
Absorption law	• A + AB = A • A(A+B) =A • $\bar{A}+AB=\bar{A}+B$ • $\bar{A}+A\bar{B}=\bar{A}+\bar{B}$
Idempotence Law	• ORing-A+A+A + ... = A • ANDing- A.A.A .... = A
AND Operation Theorem	• A.0 = 0 • A.1 = A • A.A = A • $A.\bar{A}=0$
OR Operation Theorem	• A+A = A • A+0 = A • A+1 = 1 • $A+\bar{A}=1$
Transposition Theorem	• (A+B).(A+C) = A + BC
Consensus or Redundancy Theorem	• $AB+\bar{A}C+BC=AB+\bar{A}C$
Demorgan's Theorem	• $\overline{A.B}=\bar{A}+\bar{B}$ • $\overline{A+B}=\bar{A}.\bar{B}$
Duality Theorem	• (•) ⟷ (+) •(0) ⟷ (1) AND ↔ OR • Taking all literals as it is.
Complementary Theorem	•(•) ⟷ (+) •(0) ⟷ (1) • Complement literals individually
Involution Theorem	• $\bar{\bar{A}}=A$

Note :-

- ➢ Maximum possible minterm or maxterm = 2^n
- ➢ Maximum possible logical expression = 2^{2^n}
- ➢ Maximum possible self dual expression = $2^{2^{n-1}}$
- ➢ AND, OR, NAND, NOR, XOR and X-NOR- Gate follow commutative law
- ➢ AND, OR, XOR, and X-NOR- Gate follow associative law
- ➢ NAND and NOR-Gate does not follow associative law

☐ Logic Gates

- ➢ Logic Gate is a electronics switch which performs the arithmetic and logic function.

■ Basic Gates

<table>
<tr><th>Gate</th><th>Symbol</th><th>Diode circuit</th><th>Transistor</th><th>Truth table</th><th>Switch table</th></tr>
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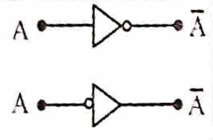
<td>
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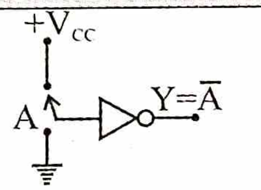
<td>
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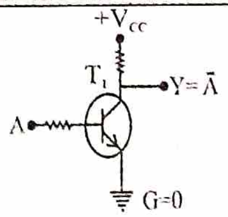
<td>
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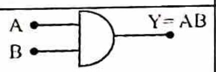
<td><table><tr><th>A</th><th>T₁/D₁</th><th>Y</th></tr><tr><td>Low</td><td>OFF</td><td>High</td></tr><tr><td>High</td><td>ON</td><td>Low</td></tr></table></td></tr>
<tr><td>AND</td>
<td>
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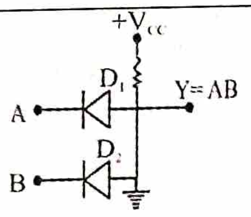
<td>
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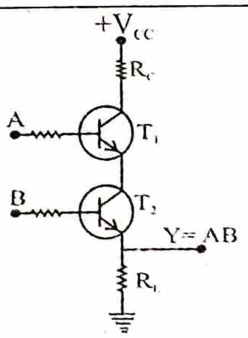
<td>
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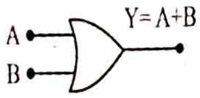
<td><table><tr><th colspan="2">Input</th><th>Output</th></tr><tr><td>A</td><td>B</td><td>Y = AB</td></tr><tr><td>0</td><td>0</td><td>0</td></tr><tr><td>0</td><td>1</td><td>0</td></tr><tr><td>1</td><td>0</td><td>0</td></tr><tr><td>1</td><td>1</td><td>1</td></tr></table></td>
<td><table><tr><th>A</th><th>B</th><th>T₁/D₁</th><th>T₂/D₂</th><th>Y</th></tr><tr><td>Low</td><td>Low</td><td>ON</td><td>ON</td><td>Low</td></tr><tr><td>Low</td><td>High</td><td>ON</td><td>OFF</td><td>Low</td></tr><tr><td>High</td><td>Low</td><td>OFF</td><td>ON</td><td>Low</td></tr><tr><td>High</td><td>High</td><td>OFF</td><td>OFF</td><td>High</td></tr></table></td></tr>
<tr><td>OR</td>
<td>
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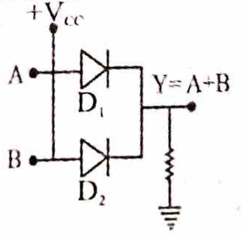
<td>
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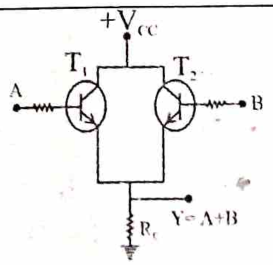
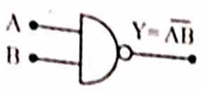
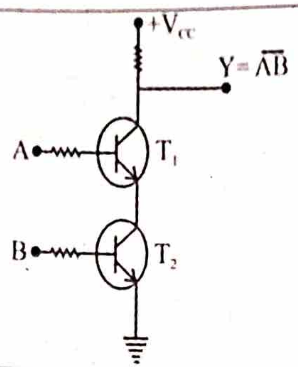
<td>
</td>
<td><table><tr><th colspan="2">Input</th><th>Output</th></tr><tr><td>A</td><td>B</td><td>Y = A+B</td></tr><tr><td>0</td><td>0</td><td>0</td></tr><tr><td>0</td><td>1</td><td>1</td></tr><tr><td>1</td><td>0</td><td>1</td></tr><tr><td>1</td><td>1</td><td>1</td></tr></table></td>
<td><table><tr><th>A</th><th>B</th><th>T₁/D₁</th><th>T₂/D₂</th><th>Y</th></tr><tr><td>Low</td><td>Low</td><td>OFF</td><td>OFF</td><td>Low</td></tr><tr><td>Low</td><td>High</td><td>OFF</td><td>ON</td><td>High</td></tr><tr><td>High</td><td>Low</td><td>ON</td><td>OFF</td><td>High</td></tr><tr><td>High</td><td>High</td><td>ON</td><td>ON</td><td>High</td></tr></table></td></tr>
</table>

Universal Gate

NAND Gate

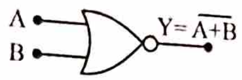

A
B
$Y = \overline{AB}$

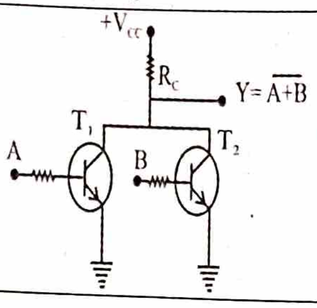

$+V_{CC}$
$Y = \overline{AB}$
A
T_1
B
T_2

Input		Output
A	B	$Y = \overline{AB}$
0	0	1
0	1	1
1	0	1
1	1	0

A	B	T_1	T_2	Y
Low	Low	OFF	OFF	High
Low	High	OFF	ON	High
High	Low	ON	OFF	High
High	High	ON	ON	Low

NOR Gate


A
B
$Y = \overline{A+B}$


$+V_{CC}$
R_C
$Y = \overline{A+B}$
T_1
T_2
A
B

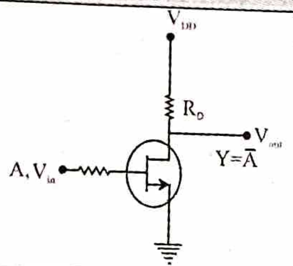
Input		Output
A	B	$Y = \overline{A+B}$
0	0	1
0	1	0
1	0	0
1	1	0

A	B	T_1	T_2	Y
Low	Low	OFF	OFF	High
Low	High	OFF	ON	Low
High	Low	ON	OFF	Low
High	High	ON	ON	Low

FET as a Switch

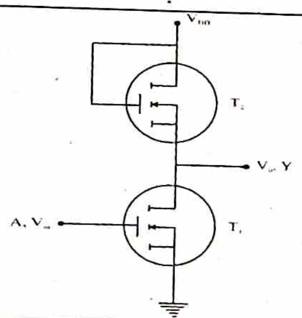
Gate | **Diagram** | **Truth Table**

JFET as NOT Gate


V_{DD}
R_D
V_{out}
$Y = \overline{A}$
A, V_{in}

A	T_1	Y
Low	OFF	High
High	ON	Low

MOSFET as NOT Gate

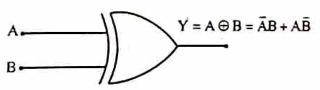

V_{DD}
T_2
V_o, Y
A, V_{in}
T_1

A	T_1	T_2	Y
Low	ON	OFF	High
High	ON	ON	Low

Special Purpose Gates

Gate | **Symbol** | **Truth Table**

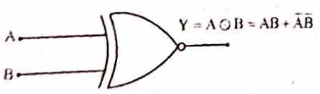
EX-OR


A
B
$Y = A \oplus B = \overline{A}B + A\overline{B}$

- ➢ In EXOR operation
- • For BUFFER CIRCUIT ⇒ Logic '0'
- • For INVERSION CIRCUIT ⇒ Logic '1'

Input		Output
A	B	$Y = A \oplus B$
0	0	0
0	1	1
1	0	1
1	1	0

EX-NOR


A
B
$Y = A \odot B = AB + \overline{A}\overline{B}$

- ➢ In EXNOR operation
- • For BUFFER CIRCUIT ⇒ Logic '1'
- • For INVERSION CIRCUIT ⇒ Logic '0'

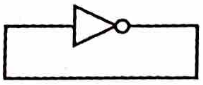
Input		Output
A	B	$Y = A \odot B$
0	0	1
0	1	0
1	0	0
1	1	1

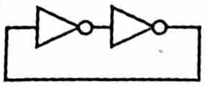
Logic gates	No. of NAND Gate required	No. of NOR Gate required
NOT	1	1
AND	2	3
OR	3	2
EX-OR	4	5
EX-NOR	5	4
NAND	1	4
NOR	4	1

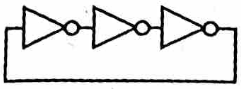
- **For Astable Multivibrator:** $\boxed{T = 2nt_{pd}}$

  Where, T= time period of square wave, n= no. of NOT-Gate, t_{pd} = Propagation delay time of each NOT-Gate

☞ Remember Point


→ Indeterminant output


→ Work as Bistable multivibrator


→ Work as Astable multivibrator, square wave generator, clock generator

- AND Gate is also called all or nothing gate
- AND Gate works as a series switch
- OR Gate is also called any or all Gate
- OR Gate works as a parallel switch
- EX-OR gate acts as odd number of "1's detector".
- EX-OR gate is used for even parity generator and detector.
- EX-OR gate is known as stair case switch.
- EX-NOR gate acts as even number of "1's detector".
- EX-NOR gate is used for odd parity generator.
- XOR-Gate is also called anti-incidental logic gate.
- $A \oplus 0 = A \rightarrow$ work as buffer
- $A \oplus 1 = \overline{A} \rightarrow$ work as inverter
- X-NOR-Gate is also called equivalence gate or equality detector or co-incident logic gate.
- $A \odot 0 = \overline{A} \rightarrow$ work as inverter
- $A \odot 1 = A \rightarrow$ work as Buffer
- NOR and NAND are special logic gates
- $A \oplus B \oplus C = A \odot B \odot C$
- $A \oplus A \oplus A \oplus \ldots\ldots\ldots n \text{ times} = 0, (\text{if } n = \text{even})$
  $= A, (\text{if } n = \text{odd})$
- $A \odot A \odot A \odot \ldots\ldots\ldots\ldots n \text{ times} = 1, (\text{if } n = \text{even})$
  $= A, (\text{if } n = \text{odd})$
- $\overline{A} \oplus B = A \oplus \overline{B} = A \odot B$
- $\overline{A \oplus B} = A \odot B$
- $\overline{A} \odot B = A \odot \overline{B} = A \oplus B$

Positive logic	Negative logic	Bubbled logic
AND- Gate	OR- Gate	NOR- Gate
OR- Gate	AND- Gate	NAND- Gate
NAND- Gate	NOR- Gate	OR Gate
NOR- Gate	NAND- Gate	AND- Gate

■ Positive Logic and Negative Logic System

- **Positive logic**
- Logic '1' voltage level is higher than logic '0' voltage level
- Logic '0' voltage level is lower than logic '1' voltage level
- **Negative logic**
- Logic '0' voltage level is higher than logic '1' voltage level
- Logic '1' voltage level is lower than logic '0' voltage level

■ Representation of Boolean functions

Representation of Boolean function

↓ Cononical form
Ex:
$F(X,Y,Z) = X\overline{Y}Z + \overline{X}YZ + \overline{X}Y\overline{Z}$

↓ Minimal form
Ex:
$F(X,Y,Z) = X + Y\overline{Z} + \overline{X}Y\overline{Z}$

- Maximum no. of Boolean expression or function = 2^{2^n}
- **Sum of Product (SOP) :** Each product term is known as minterm. SOP form (Σ_m) is used when output is logic 1. Ex.- $(A\overline{B}C) + (\overline{A}BC) + (ABC)$
- **Product of Sum (POS) :** Each product term is known as maxterm. POS form (Π_M) is used when output is logic '0'.

  Ex.- $(A + \overline{B} + C).(\overline{A} + B + C).(A + B + C)$

☞ Remember Point

- Maximum possible minterm or maxterm = 2^n
- Maximum possible self dual function = $2^{2^{n-1}}$
- AND-OR logic = NAND-NAND logic (Used in SOP).
- OR-AND Logic = NOR-NOR logic (Used in POS).

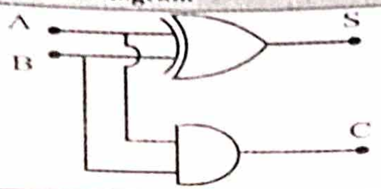
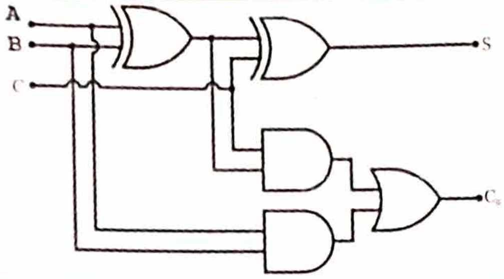
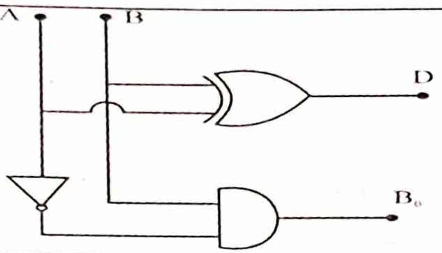
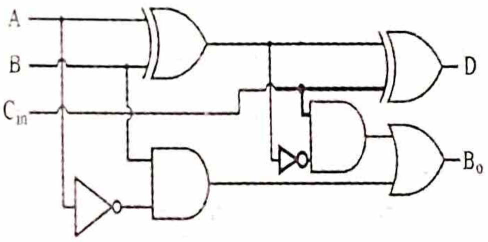
■ Karnaugh Map (K - Map)

- A systematic & simple way of minimization of Boolean algebra.
- Minimization using K-map, the solution is not unique.
- "Gray Code" is used in K-map.
- Number of cells = 2^n, n = Number of variables.
- **Don't Care** - Considered when this is helping in minimization of Boolean algebra.
- Implicants = Number of minterms/maxterms
- Prime implicants = Number of pairs
- Essential Prime Implicants= Number of prime implicants without redundant terms

❑ Digital Logic Circuits

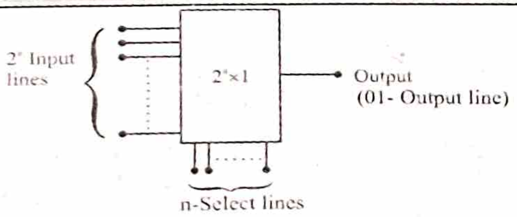
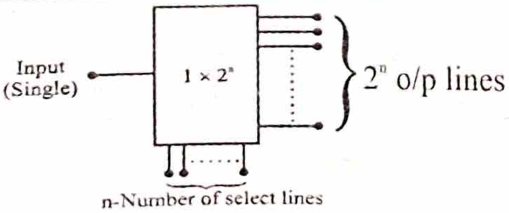
Combinational Circuit	Sequential Circuit
Present output depends only on present input.	Present output depends on both present input as well as past output.
No memory present.	Memory is present.
Faster.	Slower.
Easy to design.	Harder to Design.
No feedback present.	Feedback present.
No clock pulse required.	Clock pulse required.
Arithmetic operation and Boolean operation.	Data storing system.
Ex.- Adder, Substractor, Decoder, Encoder, Comparator MUX, D-MUX, parallel adder, ROM, RAM etc.	**Ex.-** Flip-flop, Latch, Counter, Register, serial adder etc.

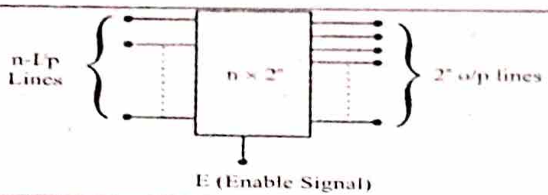
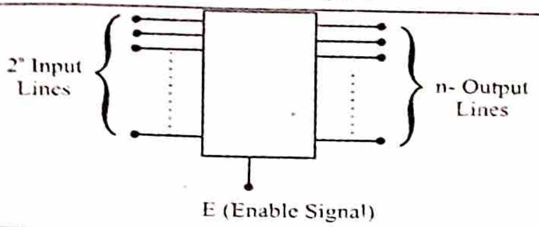
Combinational Circuits

	Circuit Diagram	Formula	Implement by
Half Adder		$S = \bar{A}B + A\bar{B} = A \oplus B$ $C = A.B$	• 5- NAND gates • 5- NOR gates • 3- (2 × 1) MUX • 2- (4×1) MUX
Full Adder		$S = A \oplus B \oplus C$ $= \bar{A}\bar{B}C + \bar{A}B\bar{C} + A\bar{B}\bar{C} + ABC$ $C_o = (A \oplus B).C + AB$ $= AB + BC + CA$	• 2- H.A+ 1 OR gate • 9- NAND gate • 9- NOR gate • 7- (2 × 1) MUX
Half subtractor		$D = \bar{A}B + A\bar{B} = A \oplus B$ $B_o = \bar{A}B$	• 5- NAND gates • 5- NOR gates • 3- (2 × 1) MUX • 2- (4×1) MUX
Full subtractor		$D = A \oplus B \oplus C$ $= \bar{A}\bar{B}C + \bar{A}B\bar{C} + A\bar{B}\bar{C} + ABC$ $B_0 = (A \odot B).C + \bar{A}B$ $= \bar{A}B + \bar{A}C + BC$	• 2- H.S + 1 OR gates • 9- NAND gates • 9- NOR gates • 7- (2 × 1) MUX

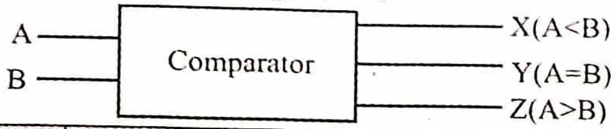
- **In parallel adder for two n-bits numbers requires-**

➢ n Full Adder ➢ (n–1) F·A + 1 H·A ➢ (2n–1) H·A + (n–1) OR Gate

	Circuit Diagram	Specification
MUX	 2^n Input lines $2^n \times 1$ Output (01- Output line) n-Select lines	➢ Named as- • Data Selector circuit • Many to One circuit • Universal logic circuit • Parallel to serial converter • Wave form generator • Data Routing • $m = 2^n$ = no. of input lines, no. of output line = 1 n = number of select lines
D-MUX	 Input (Single) 1×2^n 2^n o/p lines n-Number of select lines	➢ Named as - • Data Distributor circuit • One to many circuit • Serial to Parallel Converter • Single Input to multiple output • No. of input line =1, no. of output lines = 2^n No. of select lines = n
Decoder		➢ It is a combinational logic circuit that converts binary information from n bit input lines to a maximum 2^n o/p lines ➢ Decoders are used to convert a particular code- • Binary to octal (3×8 lines decoders) • Binary to Hexadecimal (4×16 line decoders)

		• BCD to decimal (4×10 line decoders) • BCD to 7-Segment display. • The total number of output line $m \leq 2^n$ • Decoders are widely used memory system of computer.
Encoder		➢ Inversion of Decoder circuit is known as Encoder. ➢ Encoder is used to convert other codes to binary such as - • Octal to Binary encoder (8×3 lines) • Decimal to BCD encoder (10×4 lines) • Hexadecimal to Binary encoder (16×4 lines)

■ Magnitude Comparator

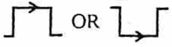


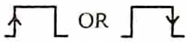
A	B	X	Y	Z
0	0	0	1	0
0	1	1	0	0
1	0	0	0	1
1	1	0	1	0
Output expression		$\bar{A}B$	$\bar{A}\bar{B}+AB=A\odot B$	$A\bar{B}$

❑ Sequential Circuits

Latch	Flip-flop
Latches use level triggering	Flip-flops use edge triggering.
No clock pulse	Clock pulse
Build from gates	Build from latch
The output changes as per the input till enable is high.	The output changes as per the input only at triggering point.
Buffer	• 1 bit memory element. • 2 Stable states • Bi-stable Multi-vibrator
Output can not predict	Output can predict (0/1)

■ **Triggering :** Triggering is used to initiate the operation of latches or flip-flops.

- **Level trigger** 

➢ **Edge trigger** 

■ Clock In Flip-Flop

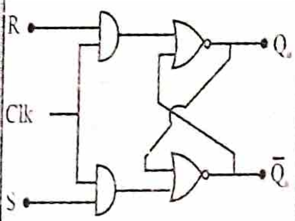
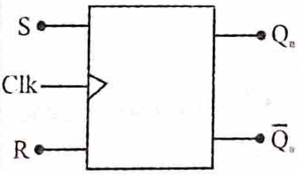
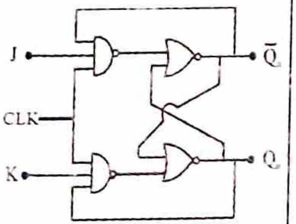
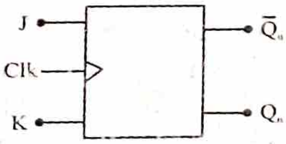
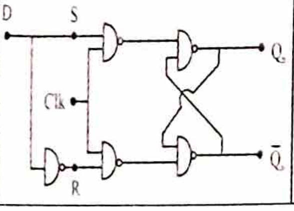
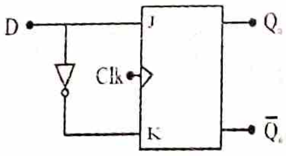
- **Setup Time :** The time period required to hold the incoming data before the arrival of clock pulse.

➢ This is of the order of 50ns.

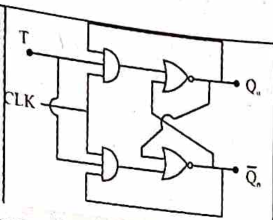
- **Hold Time :** The time period required to hold the incoming signal information after the arrival of clock pulse.

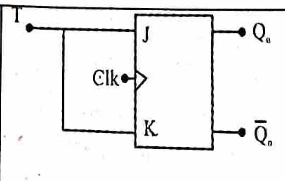
➢ This is in order of 10-20 ns.

➢ Setup Time > Hold Time.

<table>
<tr><th>Flip-Flop</th><th>Logic Diagram</th><th>Graphical Diagram</th><th>Characteristics Equation</th><th>Truth Table</th></tr>
<tr><td>SR</td><td> </td><td> </td><td>$Q_{n+1} = S + \bar{R}Q_n$</td><td><table>
<tr><th>Clock</th><th>S</th><th>R</th><th>Q_{n+1}</th><th>State</th></tr>
<tr><td>1</td><td>0</td><td>0</td><td>Q_n</td><td>Hold state</td></tr>
<tr><td>1</td><td>0</td><td>1</td><td>0</td><td>Reset state</td></tr>
<tr><td>1</td><td>1</td><td>0</td><td>1</td><td>Set state</td></tr>
<tr><td>1</td><td>1</td><td>1</td><td>Invalid</td><td>Forbidden state</td></tr>
</table></td></tr>
<tr><td>JK</td><td> </td><td> </td><td>$Q_{n+1} = J\bar{Q}_n + \bar{K}Q_n$</td><td><table>
<tr><th>Clock</th><th>J</th><th>K</th><th>Q_{n+1}</th><th>State</th></tr>
<tr><td>1</td><td>0</td><td>0</td><td>Q_n</td><td>Hold state</td></tr>
<tr><td>1</td><td>0</td><td>1</td><td>0</td><td>Reset state</td></tr>
<tr><td>1</td><td>1</td><td>0</td><td>1</td><td>Set state</td></tr>
<tr><td>1</td><td>1</td><td>1</td><td>$\bar{Q}_n$</td><td>Toggle state</td></tr>
</table></td></tr>
<tr><td>D Flip-flop</td><td> </td><td> </td><td>$Q_{n+1} = D$</td><td><table>
<tr><th>Clock</th><th>D</th><th>Q_{n+1}</th></tr>
<tr><td>0</td><td>X</td><td>Q_n</td></tr>
<tr><td>1</td><td>0</td><td>0</td></tr>
<tr><td>1</td><td>1</td><td>1</td></tr>
</table></td></tr>
</table>

T flip-flop





$$Q_{n+1} = \bar{T}Q_n + T\bar{Q}_n$$
$$= T \oplus Q_n$$

Clock	T	Q_{n+1}	State
0	X	Q_n	Previous state
1	0	Q_n	Hold state
1	1	$\bar{Q}_n$	Toggle state

Conversion of Flip-flop

Desired flip-flop / Given Flip-flop	SR Flip-flop	D Flip-flop	JK Flip-flop	T Flip-flop
SR Flip-flop		$S = D$ $R = \bar{D}$	$S = J\bar{Q}_n$ $R = KQ_n$	$S = T\bar{Q}_n$ $R = TQ_n$
D Flip-flop	$D = S + \bar{R}Q_n$		$D = J\bar{Q}_n + \bar{K}Q_n$	$D = T \oplus Q_n$
JK Flip-flop	$J = S$ $K = R$	$J = D$ $K = \bar{D}$		$J = T$ $K = T$
T Flip-flop	$D = S\bar{Q}_n + RQ_n$	$T = D \oplus Q_n$	$J = J\bar{Q}_n + KQ_n$	

Excitation Table

Q_n	Q_{n+1}	S	R	J	K	D	T
0	0	0	x	0	x	0	0
0	1	1	0	1	x	1	1
1	0	0	1	x	1	0	1
1	1	X	0	x	0	1	0

- **Applications of Flip-flops**

Serial and Parallel data storage, Data Transfer, Serial to Parallel Converter, Parallel to serial converter Latch, Counter, Frequency division, memory

☞ Remember Point

➢ Race-around condition occurs in JK-FF to store 1-bit of Information. [J = K = 1], $t_{pd\ (FF)} << t_{pw}$.

➢ Race-around Condition always arises in "Asynchronous circuits."

- **To Avoid Race Around -**

➢ $t_{pw} < t_{pd\ (FF)} < T$ ➢ Edge triggering

➢ Master-Slave FF

☐ Registers

➢ Register is a memory device, which is used for data storage & shifting.

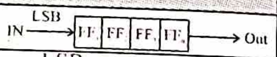
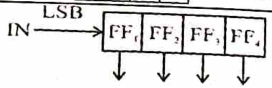
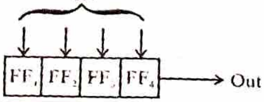
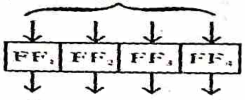
➢ Register is a group of flip-flops & gates.

➢ For n-bit data, the n-flip-flops are required.

Shift Register

➢ Data can be shifted by single bit.

- **Four types of shift Registers**

Register	Presentation	Clock pulse Input	Clock pulse Output
SISO		n	(n–1)
SIPO		n	0
PISO		1	(n–1)
PIPO		1	0

➢ **Time delay for SISO shift register-**

$$\Delta t = N \times T = N \times \frac{1}{f_c}$$

N = Number of FFs. f_c = Clock frequency

T = Time period of Clock pulse

➢ All shift Registers made of JK-FFs.

➢ In storage registers mostly D flip-flops are used.

☐ Counters

➢ Counter is formed by the cascading of FFs.

- **Counter are basically used for –**

➢ Counting of the number of clock pulses.

➢ Frequency division ➢ Timers ➢ In RADAR

➢ Frequency Measurement ➢ Wave form generation

➢ In each count the binary data is known as "State of counter."

➢ Number of states counted by a counter is known as 'modules of counter'.

If M = Modules = Mod = Total Number of states

n = Number of bits or flip-flop then $M \le 2^n$

➢ $M = 2^n \Rightarrow$ Binary Counter or ripple counter

➢ $M < 2^n \Rightarrow$ Non-Binary Counter or BCD counter

- **Counters are classified in two categories.**

i. Asynchronous Counter [Ripple Counter/Series Counter]

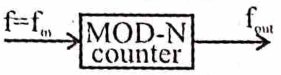
ii. Synchronous Counter [Parallel Counter]

Synchronous counter	Asynchronous counter
Same clock pulse is applied to individual flip-flop.	Clock Signal is applied only the first flip-flop.
Any sequence can be generate.	Fixed sequence [Upper or Down]
Faster	Slower
No Decoding Error	Due to propagation delay decoding error exist.
Design is complex, as number of bits increases.	Design easy, even more number of bits.
Types	**Types**
Ring Counter / End Carry Counter	Ripple Up Counter
Twisted Ring Counter / Johnson Counter	Ripple Down Counter
Synchronous-series carry counter	BCD Counter (Non-Binary)
Synchronous-parallel carry counter	Up counter
	Down counter

- **Modulus of counter**
- ➢ Known as MOD or MOD number

$\boxed{MOD \le 2^n}$

Where n = Number of flip-flop


f=fin
MOD-N counter
f out

$\boxed{f_{out} = \frac{f_{in}}{N}}$

- **Binary Counter**
  If the sequence of the states is either ascending or descending order than the counter is called binary counter. It is also called as $(2^n:1)$ scalar counter
- **Variable Modulus Counter**
- ➢ It is counter in which the maximum number of state can be changed.

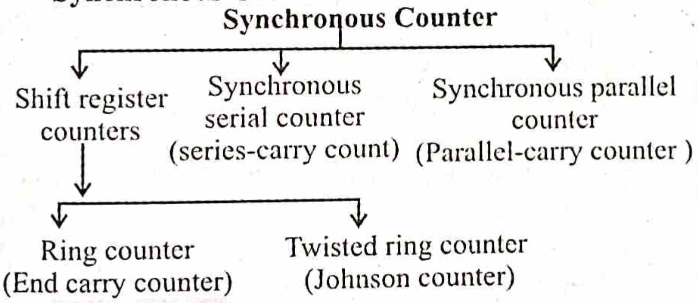
Note: The final state of the counter sequence is called the terminal counter.

- **Application of Counter**
- ➢ It is used as frequency divider circuit
- ➢ It create time delay
- ➢ It generate a required sequence bit
- ➢ **Output Frequency of two Cascaded Counters**
  Overall Mod of Counters = M.N

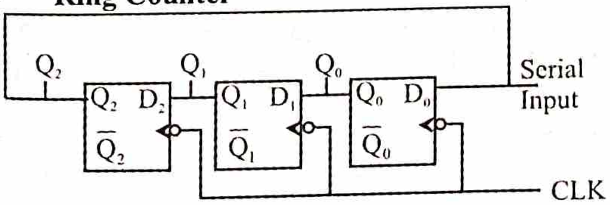
  Overall Output frequency = $f_o = \frac{f_i}{M.N}$
- ➢ For n-bits counter if delay for each Flip-flop is t_{pd} then total clock period –

$\boxed{T_{CLK} \ge n.t_{pd(ff)}}$, $\boxed{f_{CLK} \le \frac{1}{n.t_{pd(ff)}}}$ $\boxed{f_{max} = \frac{1}{n.t_{pd(ff)}}}$

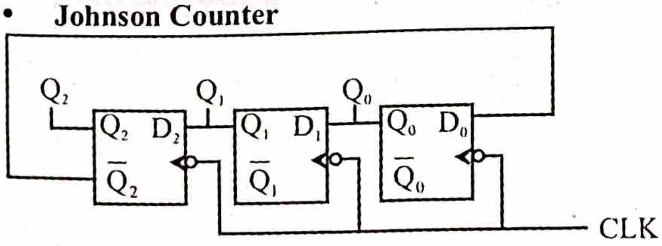
- **Synchronous Counter**


Synchronous Counter
Shift register counters
Synchronous serial counter (series-carry count)
Synchronous parallel counter (Parallel-carry counter)
Ring counter (End carry counter)
Twisted ring counter (Johnson counter)

- **Ring Counter**


Q2
Q1
Q0
Q2 D2
Q1 D1
Q0 D0
Serial Input
CLK

- ➢ Ring counter works as SISO
- ➢ It is also called n:1 counter
- **Johnson Counter**


Q2
Q1
Q0
Q2 D2
Q1 D1
Q0 D0
CLK

- ➢ Maximum count value = (2^n-1)
- ➢ Synchronous-series carry counter,

$$f_{CLK} \le \frac{1}{t_{pd(FF)} + (n-2)t_{pd(AND\,Gate)}}$$

- ➢ Synchronous-parallel carry counter,

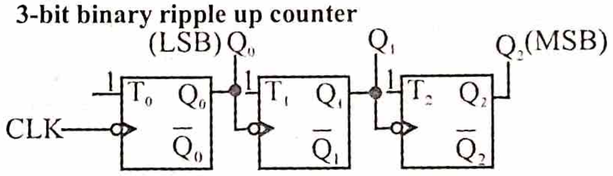
$$f_{CLK} \le \frac{1}{t_{pd(FF)} + t_{pd(AND\,Gate)}}$$

- ➢ It is the 'fastest counter".

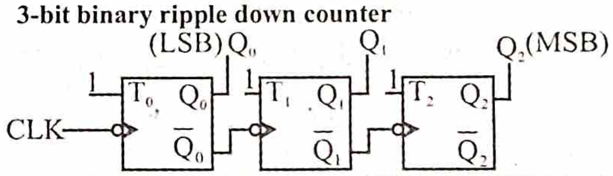
Counter	**Number of states, M**	**Unused state**	**Output frequency f_o**
BCD/Mod-10 counter	10	6, $(2^n - M)$	$f_o = \frac{f_i}{10}$
Ring counter	n	$2^n - n$	$f_o = \frac{f_i}{n}$
Johnson/Ring Twisted counter	2n	$2^n - 2n$	$f_o = \frac{f_i}{2n}$

■ **Asynchronous Counter**

- **3-bit binary ripple up counter**


(LSB) Q0
Q1
Q2(MSB)
1
T0 Q0
T1 Q1
T2 Q2
CLK

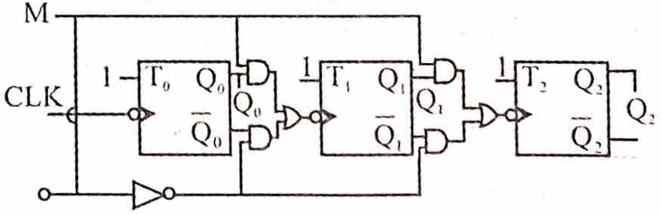
- **3-bit binary ripple down counter**


(LSB) Q0
Q1
Q2(MSB)
1
T0 Q0
T1 Q1
T2 Q2
CLK

■ Trick to Indentify Counter (Ripple counter)

Clock (Triggering)	Output	Counter
Positive edge	Q	Down-counter
	$\overline{Q}$	Up-counter
Negative edge	Q	Up-counter
	$\overline{Q}$	Down-counter

■ 3-bit Up-Down Ripple Counter


M
CLK
1
T0 Q0
T1 Q1
T2 Q2
Q0
Q1
Q2

If M = 1 ⇨ up counter, If M = 0 ⇨ down counter

☞ Remember Point

- ➢ The Ring counter and Johnson counter are not use for counting purpose.
- ➢ Johnson Counter also known as-
- ➢ Twisted Ring counter ➢ Mobies Counter
- ➢ Switch tail Ring Counter ➢ Creeping counter
- ➢ Walking counter
- ➢ In ring counter all flip-flops output frequency remain same but phase shift is different and equal to $360^0/n$, (where, n= number of state)

➢ "Lock out" problem occurs in non-binary counter.

➢ JK, SR, D and T are called synchronous Input.

➢ Reset and Set are called Asynchronous Input.

➢ "Preset" always make the output to '1'.

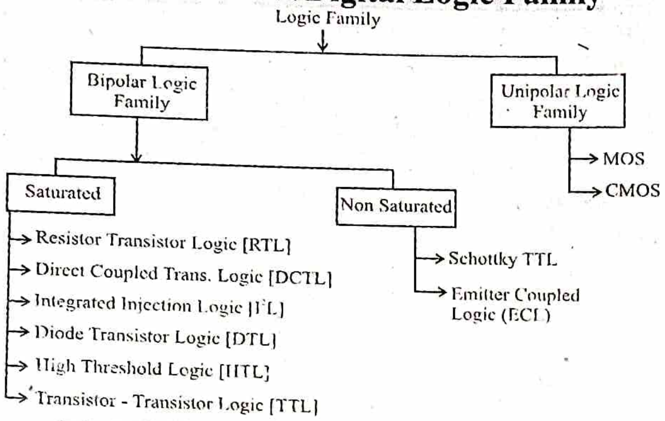
➢ "Clear" always make the output to '0'.

➢ "Glitch" is an unwanted spike in the signal.

➢ MOD-16 counter could also be called a "divide-by-16 counter".

❑ Logic Family

■ Classification of Digital Logic Family


Logic Family
Bipolar Logic Family
Unipolar Logic Family
MOS
CMOS
Saturated
Non Saturated
Resistor Transistor Logic [RTL]
Direct Coupled Trans. Logic [DCTL]
Integrated Injection Logic [I²L]
Diode Transistor Logic [DTL]
High Threshold Logic [HTL]
Transistor - Transistor Logic [TTL]
Schottky TTL
Emitter Coupled Logic (ECL)

■ Characteristics of Logic families

- **Propagation Time Delay (T_{pd})**

$$\boxed{t_{pd} = \frac{t_{PHL} + t_{PLH}}{2}} \text{ ns}$$

➢ $t_{PLH} > t_{PHL}$ (in BJT) due to reverse recovery time.

➢ $t_{PLH} < t_{PHL}$ (in FET) due to large capacitance formed.

- **Power Dissipation (P_D)**

$$\boxed{P_{D(avg)} = I_{CC} \times V_{CC} \text{ mW}}$$

$$I_{CC_{(avg)}} = \frac{I_{CCH} + I_{CCL}}{2},$$

I_{CCH} → High Level Collector Current

I_{CCL} → Low Level Collector Current

- **Figure of Merit (FOM)**

$$\boxed{FOM = t_{pd}(ns) \times P_{D(avg)}(mW)} \text{ Pico Joules}$$

➢ Also called speed power product (SPP)

➢ Minimum value of FOM is desirable.

- **Fan Out**

➢ It is defind as the maximum number of standard loads that the output of gate can drive without degrading its normal operation.

➢ fan out also called "loading factor"

$$\boxed{\text{High State Fan Out }(FO_H) = \frac{I_{OH(min)}}{I_{IH(min)}}}$$

$$\boxed{\text{Low State Fan Out }(FO_L) = \frac{I_{OL(max)}}{I_{IL(max)}}}$$

➢ Fan Out = $(FO_H, FO_L)_{minimum}$

- **Fan In**

➢ It defind as the number of inputs connected to the gate without loosing its normal operation.

- **Voltage and Current Parameter**

➢ **High level input voltage (V_{IH}):** Minimum voltage required at the input of a gate as logic 1.

➢ **Low Level Input Voltage (V_{IL}) :** Maximum voltage level that can be treated as logic 0 at the input of the gate.

➢ **High Level Output Voltage (V_{OH}):** Minimum voltage level required at the output of a gate as logic 1.

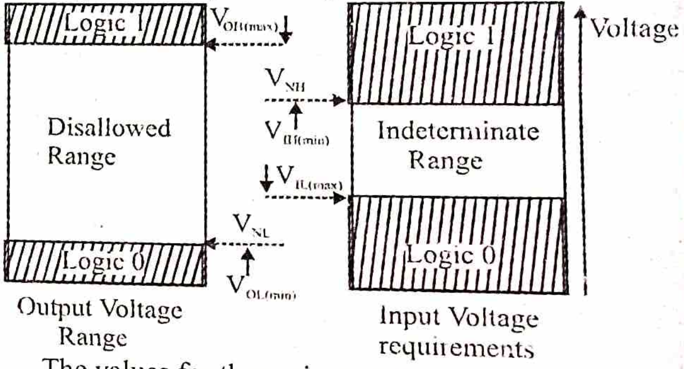
➢ **Low level output voltage (V_{OL}):** Maximum voltage level that can be treated as logic 0 at the output of the gate.

➢ **High level input current (I_{IL}):** Minimum current supplied by a driving source corresponding to low logic level.

➢ **High level output current (I_{OH}):** Maximum current which the gate can sink at high level.

➢ **Low level output current (I_{OL}):** Maximum current that the gate can sink is low level (0 level).

- **Logic level input voltage range for**


Logic 1
$V_{OH(max)}$
Logic 1
Voltage
V_{NH}
Disallowed Range
$V_{IH(min)}$
Indeterminate Range
$V_{IL(max)}$
V_{NL}
Logic 0
Logic 0
$V_{OL(min)}$
Output Voltage Range
Input Voltage requirements

The values for the various voltage parameters for the TTL logic family are as follows

(i) $V_{IH(min)} = 2.0V$ (ii) $V_{IL(max)} = 0.8V$

(iii) $V_{OH(min)} = 2.4V$ (iv) $V_{OL(max)} = 0.4V$

- **Noise-Margin :**

It is the property of a logic circuit to withstand unwanted noise voltage at input or the maximum value of noise signal that a system can reject with performance unaffected .

$V_{OH} > V_{IH} > V_{IL} > V_{OL}$

Low state N.M. = $V_{NL} = V_{IL(max)} - V_{OL(max)}$

High state N.M. = $V_{NH} = V_{OH(min)} - V_{IH(min)}$

Noise margins = $(V_{NH}, V_{NL})_{min}$

- **Bipolar Logic Families**

RTL	➢It provides wired AND logic ➢Low cost ➢Low switching speed. ➢Poor noise margin ➢Noise immunity is not good. ➢Bipolar
DCTL	➢It provides wired AND logic ➢It suffers "current hogging" ➢Crosstalk or the noise problem available ➢ Small voltage swings involved ➢Low voltage are used

DTL	➢It provides wired AND logic ➢Low Cost ➢Low operation speed ➢Bipolar
TTL	➢It is used in bus oriented system ➢Any floating input consider as logic 1 ➢It provides wired AND logic ➢Medium cost ➢ High operating speed ➢Available in different improved version. ➢ Bipolar
ECL	➢It is non-saturated logic ➢Also called current mode logic ➢Provide wired OR logic ➢Any floating input consider as logic 0 ➢Very high cost ➢Bipolar ➢Fastest logic family ➢High power dissipation.

- **Comparison of various logic families**

Logic family	**Basic gate**	**Fan out**	**Fan in**	**Power dissipa -tion (mW)**	**t_{pd} (ns)**	**Noise Marg in (V)**
RTL	NOR	3	4	10	50	0.2-0.4
DTL	NAND	3	10	1	30	0.75
HTL	NAND	10	--	55	90	4-5
TTL	NAND	10	10	10	10	0.4
ECL	OR /NOR	25	16-20	40-55	4-1	0.3
MOS	NAND /NOR	20	--	0.2-10	300	1.5
CMOS	NAND /NOR	>50	8	0-0.01	70	$\frac{V_{DD}}{2}$

➢ **Time period (ns)**

(Slowest switch)MOS > HTL > CMOS > RTL > DTL > TTL > ECL (Fastest switch)

➢ **Power dissipation**

HTL>ECL>TTL>RTL>DTL>MOS>CMOS

■ Classification of ICs –

ICs	**Equivalent to Logic Gates**	**Number of components**
Small Scale Integration [SSI]	<12	Up to 99
Medium Scale Integration [MSI]	12-99	100-999
Large Scale Integration [LSI]	100-999	1000-9999
Very Large Scale Integration [VLSI]	>1000	Above 10000

■ Some Important ICs

IC's Number	**Known As**
IC 714	Precision operational Amplifier
IC 741	OP-Amp circuit
IC 555	Timer [Pulse Generator, Oscillator]
IC 810	Audio Driver and Audio Amplifier, Pre-Amplifier
IC 7400	Quad 2 I/P NAND Gates
IC 7402	Quad 2 I/P NOR Gates
IC 7404	Hex Inverter (6 NOT Gate), Digital Inverter, Inverting Buffer
IC 7408	Quad-2 I/P AND Gates
IC 7410	Triple 3- I/P NAND Gates
IC 7420	Dual 4-I/P NAND Gates
IC 7486	Quad 2- I/P XOR Gates
IC 7476	Master Slave, for Edge Triggered
IC 7490	Decade Counter
IC 7805	Voltage Regulator
IC 7505	Switching voltage Regulators.

➢ 78 XX → Series of voltage Regulators.

➢ 74 XX → Logic Family.

☐ DACs AND ADCs

■ Specification of DAC

➢ $\text{Resolution} = \frac{V_{ref}}{2^n - 1} = \frac{V_{FS}}{\text{No. of steps}}$

➢ $\text{Resolution} = \frac{V_r}{10^n - 1}$ (for BCD input)

➢ $\%\ \text{Resolution} = \frac{\text{Resolution}}{V_{FS}} \times 100 = \frac{1}{2^n - 1} \times 100$

➢ Analog output voltage = Resolution × Decimal equivalent of binary data

➢ Full scale output voltage

= resolution × maximum decimal

$$V_{FS} = \frac{V_r}{2^n - 1} \times \left(2^n - 1\right) = V_r$$

■ Types of DAC -

- **Weighted Register DAC**

➢ Output Voltage,

$$V_o = \frac{R_f}{2^{n-1}R}\left[2^{n-1}V_{n-1} + 2^{n-2}V_{n-2} + \ldots\ldots 2^0 V_0\right]$$

➢ Decimal Equivalent of Binary Number-

$$N = \left[2^{n-1}V_{n-1} + 2^{n-2}V_{n-2} + \ldots\ldots\ldots 2^0 V\right] = \left[\sum_{i=0}^{n-1} 2^i b_i\right]$$

➢ Proportionality Factor, $K = \frac{R_f}{2^{n-1} \cdot R} \cdot V_{ref}$

➢ Input Current to OP-Amp, $I_i = \frac{V_{ref}}{2^{n-1} \cdot R} \sum_{i=0}^{n-1} 2^i b_i$

➢ Maximum Output Current, $I_{max} = \frac{V_{ref}}{2^{n-1}.R}\left(2^n - 1\right)$

➢ Here "OP-Amp" is employed as a "summing Amplifier".

$$\boxed{V_0 = \text{Resolution} \times \text{Gain} \times N}$$

☞ Remember point

➢ LSB Resistance = (2^{n-1}) × MSB Resistance

➢ Typical Value of Resistance R ranges from 2.5 kΩ - 10 kΩ.

- **R-2R Ladder D/A Converter two types**

i. **Non Inverting OP-Amp type**

➢ Analog Output Voltage,

V_{out} = Resolution × Gain × N

$$V_{out}=\frac{V_{ref}}{2^n}\times\left[1+\frac{R_f}{R_1}\right]\times N$$

$$V_{out}=\frac{V_{ref}}{2^n}\left[1+\frac{R_f}{R_1}\right]\times\left[\sum_{i=0}^{n-1}2^i b_i\right]$$

➢ $\frac{V_o}{V_{ref}}=\left(1+\frac{R_f}{R_1}\right)$

ii. **Inverting OP-Amp type**

➢ $\boxed{\frac{V_{out}}{V_{ref}}=-\frac{R_f}{R_1+R}}$

$$V_{out}=\left[\frac{V_{ref}}{2^n}\right]\times\left[\frac{-R_f}{R_1+R}\right]\times N$$

$$V_{out}=\frac{V_{ref}}{2^n}\times\left[\frac{-R_f}{R_1+R}\right]\times\left[\sum_{i=0}^{n-1}2^i b_i\right]$$

➢ Output Current, $I=\frac{V_{ref}}{2^n}\left[\sum_{i=0}^{n-1}2^i b_i\right]\times\left[\frac{1}{R_1+R}\right]$

➢ Resolution of R-2R Ladder Network is, $\frac{V_{ref}}{2^n}$.

Inverted Ladder (R-2R) type DAC

➢ $\boxed{\frac{V_o}{V_{ref}}=\frac{-R_f}{R}}$

➢ $V_o=\frac{V_{ref}}{2^n}\left[\sum_{i=0}^{n-1}2^i b_i\right]\times\left[\frac{-R_f}{R}\right]$

➢ Forward Current, $I_f=\frac{V_{ref}}{2^n}\left[\sum_{i=0}^{n-1}2^i b_i\right]\times\frac{1}{R}$

➢ **Settling Time :** The time required for output analog voltage to settle at $\pm\frac{1}{2}$ LSB of FSV is known as settling time.

Specifications of ADC

➢ Voltage Range, $V_{range}=V_{max}-V_{min}$

➢ Resolution = $\frac{V_{range}}{2^n-1}$

➢ $\boxed{\%\text{Resolution}=\frac{1}{2^n-1}\times 100}$

➢ Dynamic Range = (6n + 1.8) dB

➢ Digital output = (Number of steps) Binary.

Types of ADC

1. **Counter type ADC-**

➢ Known as ramp type ADC

➢ Conversion time depends on input analog voltage.

Disadvantages

➢ Larger Conversion Time

➢ Slow Speed Operation

2. **Flash type ADC**

➢ Also known as simultaneous type ADC.

➢ Resolution $R=\frac{V_r}{2^n}$ = step size

➢ For n bit conversion Flash Type ADC-

➢ Number of Comparator = 2^n-1

➢ Number of Resistors = 2^n

➢ Priority Encoder = $2^n\times n$

➢ It is fastest among all type ADC.

➢ It is also known as parallel computer type ADC.

3. **Successive Approximation Resistor type (SAR)**

➢ It is also known as SAR Type ADC.

➢ In SAR Conversion time is independent of input analog voltage.

➢ Maximum conversion time = $n\times T_{clk}$

4. **Dual Slope Integrating Type ADC**

➢ Highest Conversion time [10 to 100 ns]

➢ Slowest ADC among all ADCs.

➢ This ADC is used in digital "Voltmeter".

Comparison of ADCs

ADCs	Number of Clocks	Conversion time
Flash type ADC	1	T_{clk}
SAR type ADC	n	$n.T_{clk}$
Counter type ADC	2^n-1	$(2^n-1)T_{clk}$
Dual slope ADC	2^{n+1}	$(2^{n+1})T_{clk}$

☞ Remember point

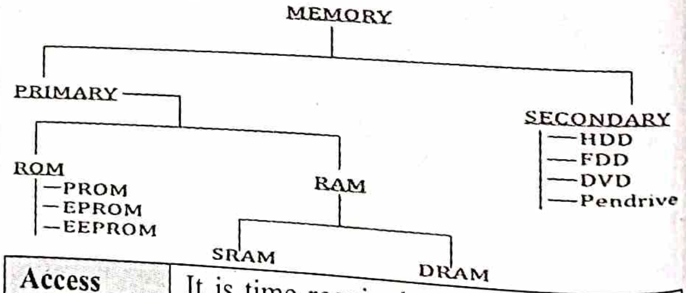
➢ Flash type ADC is the fastest but most expensive among all the ADCs.

➢ The dual slope ADC has highest accuracy.

➢ SAR type ADC is used in data acquisition applications.

➢ The Successive approximation ADC's are used in application such as data loggers and instrumentation where conversion speed is important.

Memory :



Access Time	It is time required to access a memory location for reading or writing operation. **Average Access time-** $t_{avg}=ht_c+(1-h)(t_m+t_c)$ h= hit ratio, t_c= cache time t_m = main memory access time.

Random Access	If the access time independent of the position.
Sequential Access memory	A memory in which the location can be accessed in a sequence only this referred to as a sequential memory.
Memory cell	A device used to store a single bit (0 or 1).
Memory word	A group of bits in a memory that represent instruction or data of some type.
Address	A number that identifies the location of word in memory.
Read operation	The operation whereby the binary word stored in a specific memory location is sensed and then transferred to another device. It is called 'Fetch operation also.
Write operation	The operation whereby a new word is placed in to a particular memory location. It is also referred to as a 'store operation.
Volatile memory	Volatile memory is a type storage whose contents are erased when the system's power turned off.
Read write memory (RWM)	Read write memory (RWM) is computer memory that can be read and written to.
Direct memory Access	DMA interface is used for transferring data directly between an external device and memory.

(DMA)	

- ➢ Cache memory is the fastest memory

- **Difference between RAM and ROM**

RAM	ROM
It is Random access memory and also called read/ write memory.	It is read only memory.
Used to store the data that has to be currently processed by CPU.	It stores the instructions required during bootstrap of the computer.
Temporary Storage	Permanent Storage.
It is volatile memory.	It is non volatile memory.

Static RAM	Dynamic RAM
Data is store like Flip-flop	Data is stored in MOS Capacitor
BJT, MOSFET are used	MOSFET is used.
Faster than DRAM	Slower than SRAM
Power dissipation is more	Power dissipation in low
Packing density is low	Packing density is high
Used as cache memory	Used as main memory.
No refreshing is required	Refreshing is required

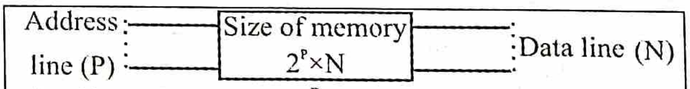
ROM (Read only memory)	PROM (Programmable read only memory)	EPROM (Erasable programmable read only memory)	EEPROM (Electrically Erasable programmable read only memory)
Data is stored by manufactured during fabrication	Data is stored by user (only one time)	Erasing is used ultraviolet (UV) light	Erasing is used electrical signal
User can't change any location	User can change location only one time	Erasing time 15-20 minutes	Erasing time in second
Marked ROM	Fusible gate	Slower	Faster (flash)

Note: PROM is generally not use in practice.

ROM	Fixed AND-Gate	Fixed OR-Gate
PROM	Fixed AND-Gate	Programmable OR-Gate
PAL	Programmable AND-Gate	Fixed OR-Gate
PLA	Programmable AND-Gate	Programmable OR-Gate

- ➢ Bit : A binary digit '0' or '1'.
- ➢ Byte : A group of eight bits (8 bit).
- ➢ Nibble : A group of four bits (4 bit).
- ➢ Word : A group of byte the compute recognizes.

- **Size of memory-**



➢ Size of memory = $2^P \times N$

Where,

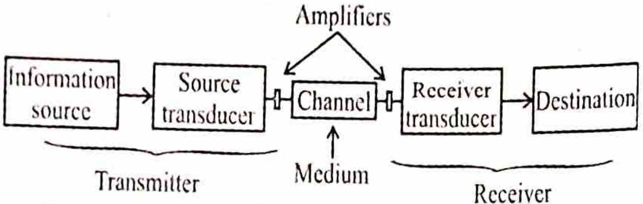
P = Number of address lines.

2^P = Number of memory location.

N = Number of data line.

COMMUNICATION ENGINEERING

- **Communication-** The process of transmitting information from source to destination or from transmitter to receiver.


Amplifiers
Information source
Source transducer
Channel
Receiver transducer
Destination
Medium
Transmitter
Receiver

- ➢ Frequency range of voice signal- 300Hz–3.4 kHz
- ➢ frequency range of audio signal- 20Hz-20kHz
- ➢ Frequency range of video signal- 0-4.5 MHz
- ➢ Voice signal is the acoustic pressure w.r.t. time
- ➢ Source transducer converts physical signal into electrical signal. (**Ex**-microphone)
- ➢ Channel is the medium through which signal propagates from one place to another place.
- ➢ Wired communication system is preferred for short distance communication only.
- ➢ For long distance communication wireless system will be used in which signal propagate through free space in the form of electromagnetic waves with the speed of light (3×10^8 m/s)
- ➢ Electromagnetic wave can travel through vacuum also with the speed of light (3×10^8 m/s)
- ➢ Receiving transducer converts electrical signal into physical equivalent signal.
- ➢ Channel bandwidth ≥ signal bandwidth

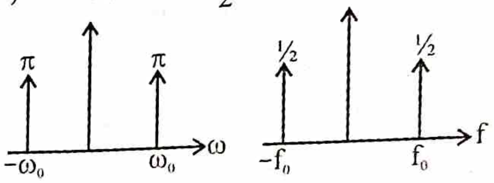
- **Some channel Bandwidth**

Co-axial cable → 0-600 MHz (Without any attenuation)
Parallel wire → 0–200 kHz
Optical fibre cable →10's of GHz

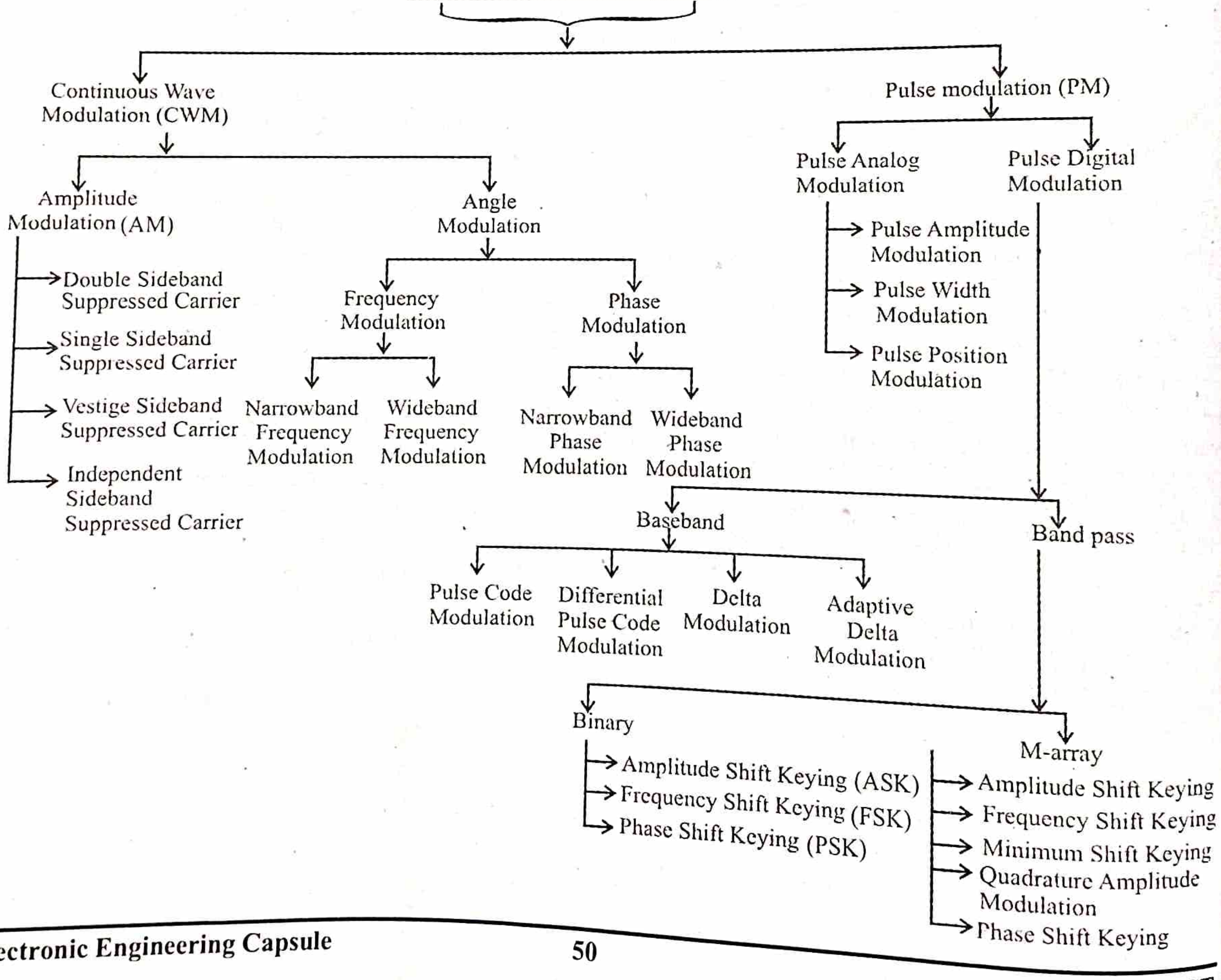
- **Modulation properties of Fourier transform**

$$x(t)\cos\omega_0 t \xrightarrow{F.T.} \pi\left[X(\omega-\omega_0)+X(\omega+\omega_0)\right]$$

$$x(t)\cos 2\pi f_0 t \xrightarrow{F.T.} \frac{1}{2}\left[X(f-f_0)+X(f+f_0)\right]$$


π
π
$-\omega_0$
ω_0
ω
½
½
$-f_0$
f_0
f

Modulation Process

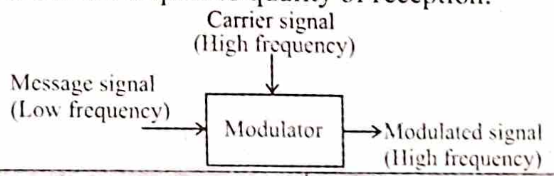

Continuous Wave Modulation (CWM)
Pulse modulation (PM)
Amplitude Modulation (AM)
Angle Modulation
Double Sideband Suppressed Carrier
Single Sideband Suppressed Carrier
Vestige Sideband Suppressed Carrier
Independent Sideband Suppressed Carrier
Frequency Modulation
Phase Modulation
Narrowband Frequency Modulation
Wideband Frequency Modulation
Narrowband Phase Modulation
Wideband Phase Modulation
Pulse Analog Modulation
Pulse Digital Modulation
Pulse Amplitude Modulation
Pulse Width Modulation
Pulse Position Modulation
Baseband
Band pass
Pulse Code Modulation
Differential Pulse Code Modulation
Delta Modulation
Adaptive Delta Modulation
Binary
M-array
Amplitude Shift Keying (ASK)
Frequency Shift Keying (FSK)
Phase Shift Keying (PSK)
Amplitude Shift Keying
Frequency Shift Keying
Minimum Shift Keying
Quadrature Amplitude Modulation
Phase Shift Keying

- **Modulation-** Modulation is a process by which some characteristics parameters of a carrier wave is varied in accordance with the modulating wave.
- **Demodulation-**The process of recovering the message signal from the modulated wave is known as demodulation (reverse process of modulation).
- **Types of modulation**

Single tone modulation	If message signal contains single frequency component it is correspond to single tone modulation.
Multi-tone modulation	If message signal contains multiple frequency components then it is correspond to multi-tone modulation.

- **Need of Modulation-**

➢ Modulation reduces the height of Antenna.
➢ Modulation avoids mixing of signals.
➢ Modulation increases the range of communication.
➢ Modulation allows adjustments in the bandwidth and multiplexing of signals.
➢ Modulation improves quality of reception.



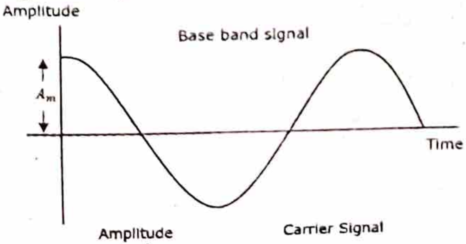
Base-band signal	**Band-pass signal**
It has significant frequency component near zero or low frequency.	It has significant frequency component away from zero frequency or low frequency.
Minimum frequency = 0 Hz	Minimum frequency $\neq 0$Hz

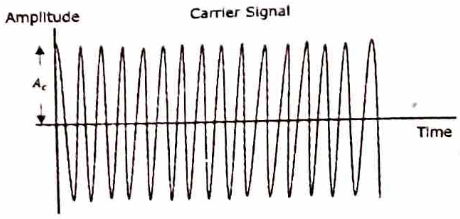
Note:

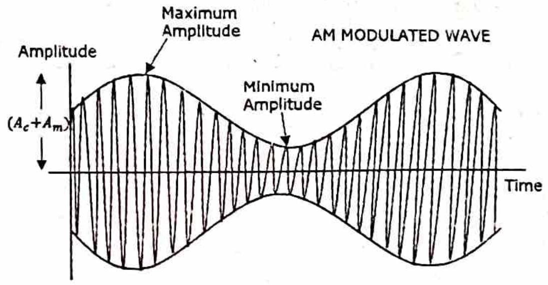
➢ Base-band communication doesn't use modulation technique.
➢ Band-pass communication use modulation technique.

❑ Amplitude modulation (AM)-

The AM is process by which peak amplitude of the carriers signal is varied with respect to message signal amplitude variation.







■ Double Sideband Full Carrier (DSB-FC)

➢ Message signal $m(t) = A_m\cos(2\pi f_m t)$
➢ Carrier signal $c(t) = A_c \cos(2\pi f_c t)$
➢ $\boxed{S_{AM}(t) = A_c\left[1+k_a m(t)\right]\cos 2\pi f_c t}$

Where, k_a = Amplitude sensitivity

$$S_{AM}(t) = A_c(1+\mu\cos\omega_m t)\cos\omega_c t$$

Where, μ= modulation index

$$S_{AM}(t) = A_c\cos 2\pi f_c t + \frac{A_c\mu_a}{2}\cos 2\pi(f_c+f_m)t$$

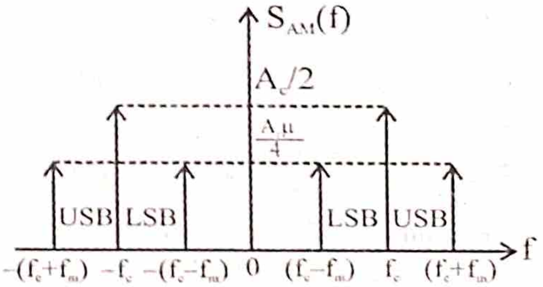
$$+\frac{A_c\mu_a}{2}\cos 2\pi(f_c-f_m)t$$

■ Frequency Spectrum of AM signal

$$S_{AM}(f) = \frac{A_c}{2}\left[\delta(f-f_c)+\delta(f+f_c)\right]+$$

$$\frac{A_c\mu}{4}\left[\delta\{f-(f_c-f_m)\}+\delta\{f+(f_c-f_m)\}\right]+$$

$$\frac{A_c\mu}{4}\left[\delta\{f-(f_c+f_m)\}+\delta\{f+(f_c+f_m)\}\right]$$



➢ Bandwidth of AM = USB-LSB $=2f_m$
➢ Carrier frequency component exists of f_c.
➢ Upper side band frequency components exist above f_c. (f_c to f_c+f_m)
➢ Lower side band frequency components exist below f_c. (f_c to f_c-f_m)

- **Modulation Index of AM**

$$\mu = \frac{A_{max}-A_{min}}{A_{max}+A_{min}} = \frac{A_m}{A_c} \because A_C = \frac{A_{max}+A_{min}}{2}$$

➢ Modulation index gives the depth to which the carrier signal is modulated.
➢ Range of modulation index is, $\boxed{0 \le \mu \le 1}$
➢ For multi-tone message signal total modulation index (μ_t) is

$$\mu_t = \sqrt{\mu_1^2+\mu_2^2+\mu_3^2+\ldots\ldots}$$

- ➢ Critical Modulation ($\mu = 1$) → $\boxed{A_m = A_c}$
- ➢ Under Modulation ($\mu < 1$) → $\boxed{A_m < A_c}$
- ➢ Over Modulation ($\mu > 1$) → $\boxed{A_m > A_c}$
- ➢ In over modulation reconstruction of message signal is complex
- ➢ In over modulation, the signal gets distorted and this is also known as non-linear distortion or envelope distortion.
- ➢ Efficiency (η) $\frac{P_{SB}}{P_T} = \frac{\mu^2}{2+\mu^2}$

- **Power of AM signal**

Carrier power	$\boxed{P_c = \frac{A_c^2}{2R}}$
Total power	$\boxed{(P_T) = P_c\left(1+\frac{\mu^2}{2}\right)}$ $\boxed{P_t = P_c + P_{USB} + P_{LSB}}$
Total transmitted current	$\boxed{I_T = I_c\sqrt{1+\frac{\mu^2}{2}}}$
Total sideband power	$\boxed{P_{SB} = P_{LSB} + P_{USB}}$ $\boxed{P_{SB} = \frac{A_c^2\mu^2}{4R} = \frac{P_c\mu^2}{2}}$
Single sideband power	$\boxed{P_{USB} = P_{LSB} = \frac{A_c^2\mu^2}{8R}}$ $\boxed{= \frac{P_c\mu^2}{4}}$

➢ $P_{SB} = 33.33\%$ of P_t ➢ $P_c = 66.66\%$ of P_t [when μ=1]

- % Power saving $= \frac{\text{Power saved}}{\text{Total power}} \times 100\%$

For DSB-SC:-

$$\%\text{ Power saving} = \frac{2}{2+\mu_a^2} \times 100\%$$

$$= \frac{P_c}{P_t} \times 100\%$$

For SSB-SC:-

% Power saving

$$= \frac{4+\mu^2}{4+2\mu^2} \times 100\% = \frac{P_c + P_{LSB}}{P_t} \times 100\%$$

- **Order of power saving in AM**

$(SSB-SC) > (VSB-SC) > (DSB-SC) > (DSB-FC)$

- **Order of power transmitter –**

$P_{AM} > P_{DSB} > P_{VSB} > P_{SSB}$

- **Transmission efficiency –**

Sinusoidal wave	$\boxed{\eta = \frac{\mu_a^2}{2+\mu_a^2}}$
Square wave	$\boxed{\eta = \frac{\mu_a^2}{1+\mu_a^2}}$
Triangular wave	$\boxed{\eta = \frac{\mu_a^2}{3+\mu_a^2}}$

- **Order of bandwidth in AM system:-**

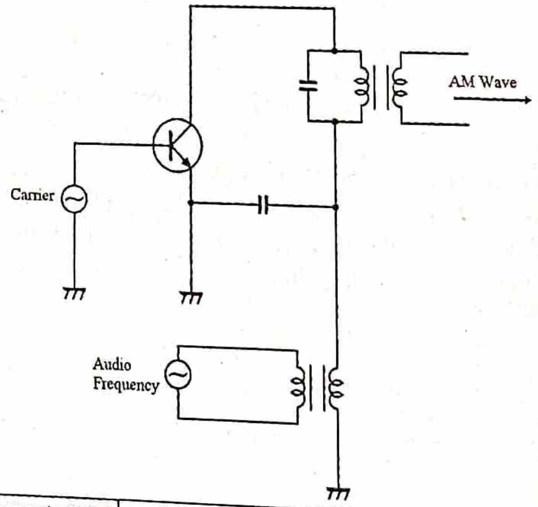
$BW_{AM \& DSB-SC} > BW_{VSB} > BW_{SSB-SC}$

- ➢ The shape of envelope is same as the shape of baseband signal.
- ➢ More power dissipation.
- ➢ Easy modulation and de-modulation.
- ➢ Transmission bandwidth $\boxed{(B.W.)_T = 2f_m}$ Hz
- ➢ Known as A3E.

Advantage of AM	➢ Demodulation become simple. ➢ AM is used for long distance communication.
Disadvantage of AM	➢ Power wastage takes place. ➢ AM need large bandwidth ➢ AM wave gets affected due to noise. ➢ Quadrature null effect is present
Application	➢ AM preferred in broad casting due to AM receiver simple & cheaper.

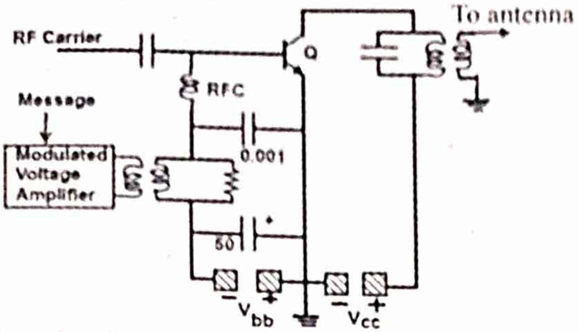
■ Generation of AM wave

- **Linear method – i.** Collector modulation **ii.** Base Modulation **iii.** Switching modulation
- **Collector modulation**



Advantage	• High collector efficiency (due to class C amplifier). • Power output per transistor is high • Better linearity
Drawback	• More modularity power is needed
Application	• In AM broadcasting

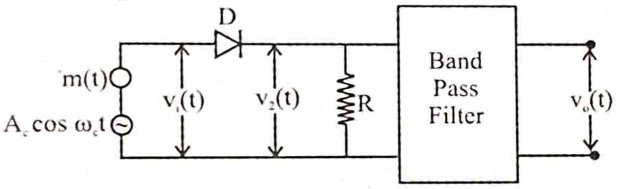
- **Base Modulation**


To antenna
RF Carrier
Q
RFC
Message
Modulated Voltage Amplifier
0.001
50
+
−
V_bb
+
−
V_cc

- ➢ Low level modulation method
- ➢ Message signal is applied in series with transistor base supply voltage. So base bias voltage $V_{BB} \propto$ signal voltage
- ➢ RF signal is applied also to the base means all main processor will be done at the transistor base terminal.
- ➢ Modulated signal is amplify by class-B amplifier.

advantage	• Needs of low power as compared to collector modulation
Drawback	• Less output power as compared to collector modulation. • Less collector efficiency with respect to collector modulation. • Less linear as to collector modulation.
Application	• TV transmission • SSB generation

- **Switching modulator-**


D
m(t)
$A_c \cos \omega_c t$
$v_1(t)$
$v_2(t)$
R
Band Pass Filter
$v_o(t)$

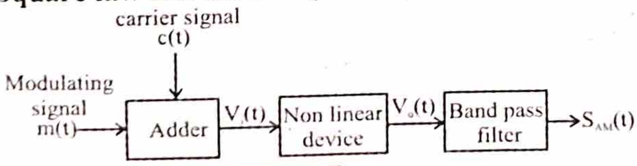
$$v_o(t) = \frac{A_c}{2}\cos 2\pi f_c(t) + \frac{2}{\pi} m(t)\cos 2\pi f_c(t) v_0$$

$$= \frac{A_c}{2}\left[1 + \frac{4}{\pi A_c} m(t)\right]\cos\omega_c(t)$$

$$\boxed{k_a = \frac{4}{\pi A_c}}$$

- ➢ For proper generation of AM signal in case of switching modulation is $\boxed{f_c > 2f_m}$
- ➢ It is similar to the square low modulator. The only difference is that in square law modulation, the diode is operated in a non-linear mode whereas in the switch modulator the diode has to operate as an ideal switch.

- **Square law modulation (Non linear method)-**


carrier signal
c(t)
Modulating signal
m(t)
Adder
$V_i(t)$
Non linear device
$V_o(t)$
Band pass filter
$S_{AM}(t)$

$$\boxed{v_o(t) = a_1 v_i(t) + a_2 v_i^2(t)}$$

$$\boxed{k_a = \frac{2a_2}{a_1}}$$

- ➢ For proper modulation of AM signal condition for carrier frequency.

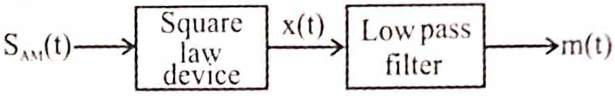
$$f_c - f_m > 2f_m$$

$$\boxed{f_c > 3f_m}$$

- ➢ Used a band pass filter (L-C tuned circuit)
- ➢ Semiconductor diode or transistor is used as non linear device.
- ➢ Output voltage ∝ (input signal)^2

■ Demodulation of AM wave

- **Square Law Detector**

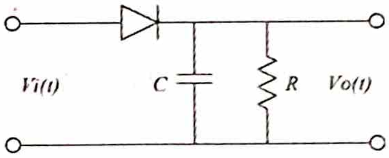

$S_{AM}(t)$
Square law device
x(t)
Low pass filter
m(t)

- ➢ To generate appropriate message signal.

$$\boxed{|k_a m(t)| << 2}$$

- ➢ Low modulation index
- ➢ Known as non-linear or small signal detector.

- **Envelope detector**

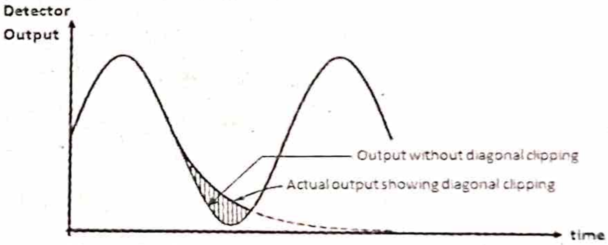


- ➢ Known as linear detector
- ➢ One diode and one RC filter are used.
- ➢ Condition for minimum distortion-

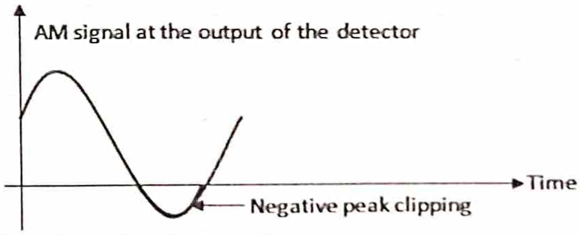
i. $R_s C << \frac{1}{f_c}$ **ii.** $\frac{1}{f_c} << R_L C << \frac{1}{f_m}$

- ➢ High power handling capacity and low distortion.
- ➢ There are two types of distortion in envelope detector-

- **Diagonal clipping**



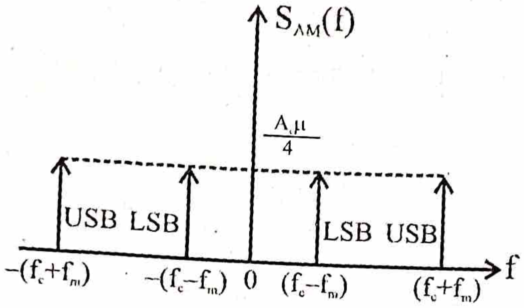
- **Negative peak clipping**



- **Synchronous detector**
- ➢ One multiplier with L.O. and LPF.

Double Sideband Suppressed Carrier (DSB-SC)

- ➢ $S_{DSB\text{-}SC}(t)=\frac{A_cA_m}{2}\left[\cos 2\pi(f_c-f_m)t+\cos 2\pi(f_c+f_m)t\right]$
- ➢ DSB-SC is a power convolution scheme not a bandwidth conversation scheme.



- ➢ Transmission bandwidth $\boxed{(BW)_T=2f_m}$ Hz
- ➢ Total transmitted power $\boxed{P_t=P_{SB}=P_{USB}+P_{LSB}}$

$$\boxed{P_t=\frac{A_c^2\mu^2}{4R}}$$

- ➢ Transmitted power saving $(P_s)=\frac{2}{2+\mu^2}$
- ➢ Power saving = 66.66%.
- **Modulation efficiency**

$$\boxed{\%\eta=\frac{P_{SB}}{P_t}\times 100\%=\frac{P_{SB}}{P_{SB}}\times 100\%=100\%}$$

- ➢ 100% of transmitted power to is used by sideband.
- ➢ The envelope shape of DSB-SC is differ to the shape of base band signal.

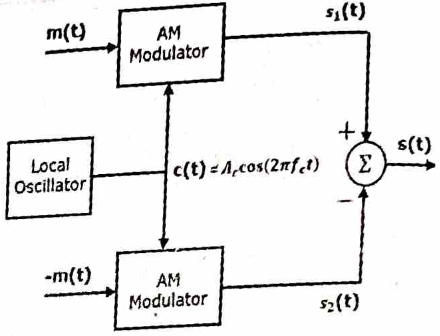
Advantage	• No wastage of power • Total power of transmitter is useful in the form of sideband.
Disadvantage	• Demodulation is complex. • It needs high channel bandwidth requirement. • Affected by the QNE (Quadrature Null Effect) • AM DSB-SC are highly noisy.
Application	• It is used for long distance communication. • It is used for quadrature carrier multiplexing.

Generation of DSB-SC- Product modulation

are two types-

1. Balance modulation 2. Ring modulation.

- **Balance modulation**



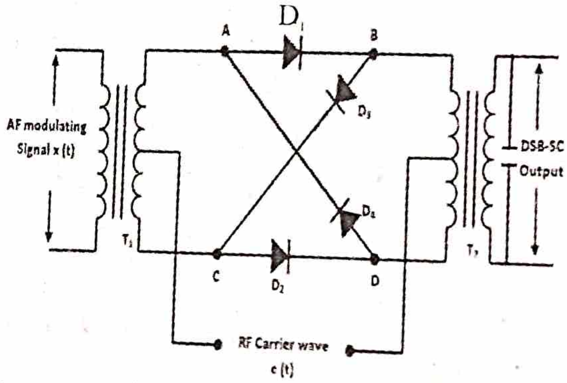
- ➢ It consists of two identical AM modulators
- ➢ Output of upper AM modulator

  $s_1(t)=A_c[1+k_a m(t)]\cos(2\pi f_c t)$
- ➢ Output of lower AM modulators

  $s_2(t)=A_c[1-k_a m(t)]\cos(2\pi f_c t)$
- ➢ The output of summer block

  $\boxed{s(t)=2A_c k_a m(t)\cos(2\pi f_c t)}$

- **Ring modulation**



- ➢ Four diodes are connected in the ring structure
- ➢ It is also known as doubler balanced modulator
- ➢ Diodes are controlled by square-wave carrier c(t) of frequency f_c.
- ➢ Two center tapped transformers are used.
- ➢ For +ve half cycle of carrier signal diode

  D_1 & $D_3\rightarrow$ ON D_2 & $D_4\rightarrow$ OFF

  The message signal is multiplied by +1
- ➢ For –ve half cycle of carrier signal.

  Diode D_2 & $D_4\rightarrow$ ON

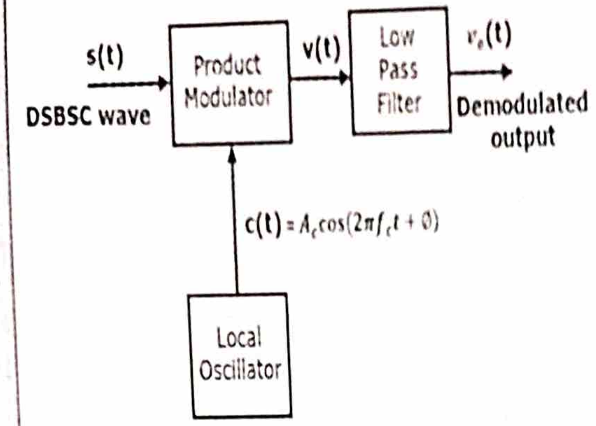
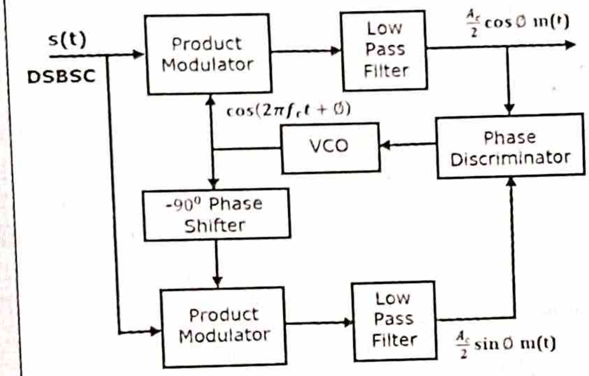
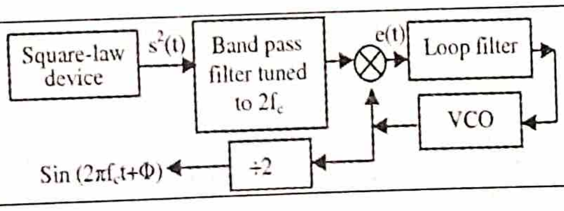
  D_1 & $D_3\rightarrow$ OFF

  The message signal is multiplied by–1 (180^0 phase shift in resulting DSBSC)

$$\boxed{c(t)=\frac{4}{\pi}\sum_{n=1}^{\infty}\frac{(-1)^{n-1}}{2n-1}\times\cos[2\pi f_c t(2n-1)]}$$

$$\boxed{s(t)=\frac{4}{\pi}\sum_{n=1}^{\infty}\frac{(-1)^{n-1}}{2n-1}\times\cos[2\pi f_c t(2n-1)]m(t)}$$

Demodulation of DSB-SC

Coherent detection or synchronous detection.	 s(t) DSBSC wave Product Modulator v(t) Low Pass Filter $v_o(t)$ Demodulated output $c(t) = A_c\cos(2\pi f_c t + \emptyset)$ Local Oscillator	- The same carrier signal (which is used for generating DSB-SC signal) is used to detect the message signal. - DSB-SC wave- $s(t) = A_c\cos(2\pi f_c t)m(t)$ - Output of the local oscillator $c(t) = A_c\cos(2\pi f_c t + \phi)$ - Output of product modulator $\boxed{v(t) = \frac{A_c^2}{2}\cos\phi\, m(t) + \frac{A_c^2}{2}\cos(4\pi f_c t + \phi)m(t)}$ - Output of low pass filter $\boxed{v_0(t) = \frac{A_c^2}{2}\cos\phi\, m(t)}$ - When, $\phi = 0^0$ then demodulated signal amplitude will be maximum. - When $\phi = \pm 90^0$, the demodulated signal amplitude will be zero. - This effect is called as quadrature null effect. (QNE)
Costas receiver	 s(t) DSBSC Product Modulator Low Pass Filter $\frac{A_c}{2}\cos\emptyset\, m(t)$ $\cos(2\pi f_c t + \emptyset)$ VCO Phase Discriminator -90^0 Phase Shifter Product Modulator Low Pass Filter $\frac{A_c}{2}\sin\emptyset\, m(t)$	- It is a phase locked loop based circuit. - In coherent detection at receiving end a carrier is required that should be phase coherent with the transmitter carrier - It can be possible, if we transmit a carrier component with the modulated signal. - But DSB-SC signal has no such component. - Costas loop has the capability to generate a coherent carrier at the receiver and therefore used for the demodulation of DSB-SC signal. - Used for carrier frequency recovery from suppressed carrier modulation signal and phase modulation signals.
Squaring loop detector	 Square-law device $s^2(t)$ Band pass filter tuned to $2f_c$ e(t) Loop filter VCO ÷2 $\sin(2\pi f_c t+\Phi)$	- It is used to recover carrier and data from modulated signal. - Square of modulated signal (done by square law device) given to a band-pass filter.

Single Sideband Suppressed Carrier (SSB-SC)

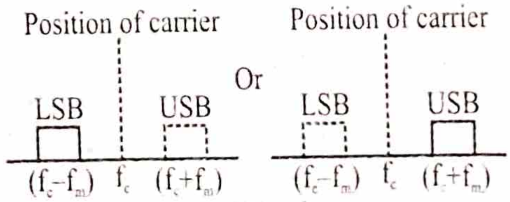
- Only one sideband is transmitted and carrier and one sideband is suppressed at the transmitter.
- No information is lost as well as more power is saved.
- $S_{SSB-SC}(t) = m(t)\cos\omega_c t \pm \hat{m}(t).\sin\omega_c t$

Where, $\hat{m}(t)$ = Hilbert transform of modulating signal

$$S_{SSB-SC}(t) = \frac{A_c A_m}{2}\cos[2\pi(f_c + f_m)t] \text{ (USB)}$$

$$S_{SSB-SC}(t) = \frac{A_c A_m}{2}\cos[2\pi(f_c - f_m)t] \text{ (LSB)}$$

- Transmission bandwidth, $\boxed{(BW)_T = f_m}$ Hz.


Position of carrier
LSB
USB
(f_c-f_m)
f_c
(f_c+f_m)
Or
Position of carrier
LSB
USB
(f_c-f_m)
f_c
(f_c+f_m)

- SSB-SC is known as J3E.
- Noise figure of merit in SSB = 1.
- SSB is known as H3E.
- Bandwidth figure of signal to noise ratio for SSB = 3kHz.
- **Total power SSB**

$$\boxed{P_t = P_{USB} = P_{LSB}} \quad \boxed{P_t = \frac{A_c^2\mu^2}{8R}}$$

- ➢ Transmission efficiency $\boxed{\%\eta = \frac{P_{SB}}{P_t} \times 100\%}$
- ➢ Transmitter power saving in SSB compared to DSB

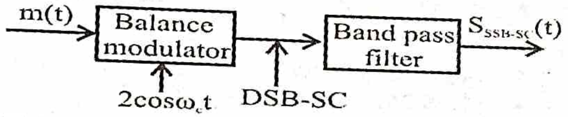
AM = $\boxed{P_s = \frac{4+\mu^2}{4+2\mu^2}}$

- ➢ Power saving = 83.33%. (for $\mu = 1$)

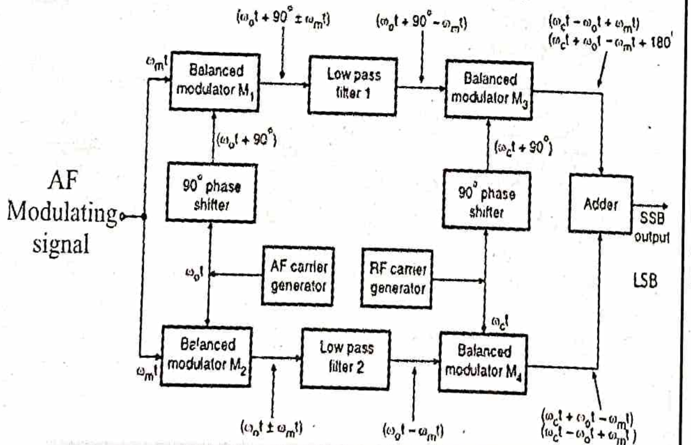
Advantage	• Transmitter power will be saved • Channel bandwidth will be saved • High power signal can be transmitted • Signal fading is less likely to occurs • Less amount of noise is present • No QNE (Quadrature Null Effect)
Drawback	• Generation and demodulation is complex and costly • Limited for voice transmission
Application	• SSB is preferred for voice transmission • Telephony communication. • Point-to-point communication. • Military communication • Radar communication • Radio communication

Generation of SSB-SC

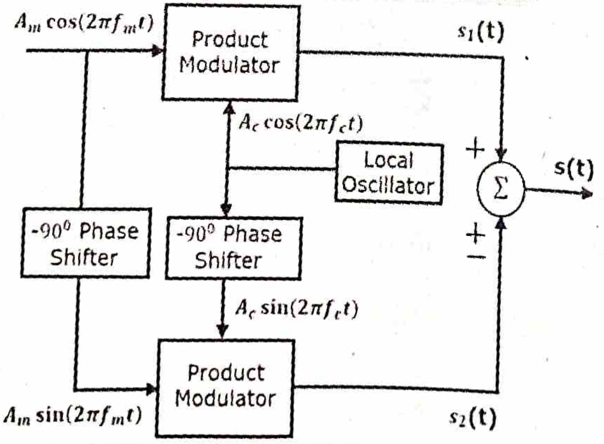
- **Filter method**


m(t)
Balance modulator
Band pass filter
$S_{SSB-SC}(t)$
$2\cos\omega_c t$
DSB-SC

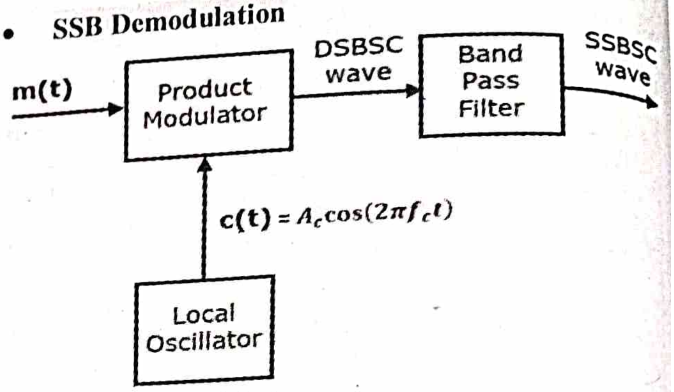
- **The third method or weaver's method**


$(\omega_0 t + 90° \pm \omega_m t)$
$(\omega_0 t + 90° - \omega_m t)$
$(\omega_c t - \omega_0 t + \omega_m t)$
$(\omega_c t + \omega_0 t - \omega_m t + 180°)$
$\omega_m t$
Balanced modulator M_1
Low pass filter 1
Balanced modulator M_3
$(\omega_0 t + 90°)$
$(\omega_c t + 90°)$
AF Modulating signal
90° phase shifter
90° phase shifter
Adder
SSB output
$\omega_0 t$
AF carrier generator
RF carrier generator
LSB
$\omega_c t$
Balanced modulator M_2
Low pass filter 2
Balanced modulator M_4
$\omega_m t$
$(\omega_0 t \pm \omega_m t)$
$(\omega_0 t - \omega_m t)$
$(\omega_c t + \omega_0 t - \omega_m t)$
$(\omega_c t - \omega_0 t + \omega_m t)$

- **Phase shift or phase cancellation method**


$A_m \cos(2\pi f_m t)$
Product Modulator
$s_1(t)$
$A_c \cos(2\pi f_c t)$
Local Oscillator
+
Σ
s(t)
+
−
-90⁰ Phase Shifter
-90⁰ Phase Shifter
$A_c \sin(2\pi f_c t)$
Product Modulator
$A_m \sin(2\pi f_m t)$
$s_2(t)$

- **SSB Demodulation**


m(t)
Product Modulator
DSBSC wave
Band Pass Filter
SSBSC wave
$c(t) = A_c \cos(2\pi f_c t)$
Local Oscillator

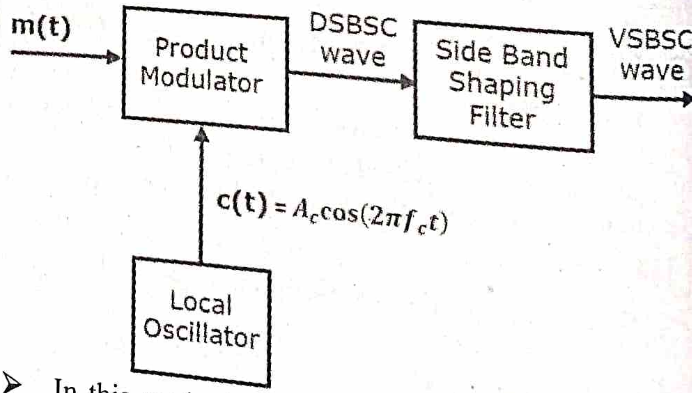
- ➢ Synchronous detector

Vestigial sideband (VSB)

- ➢ VSB known as C3F.
- ➢ One sideband is transmitted completely while only a vestige of the other sideband is transmitted.
- ➢ Transmission bandwidth, $\boxed{(BW)_T = \omega + f_v}$ Hz.
- ➢ Total channel bandwidth using vestigial lower sideband = 6 MHz.
- ➢ By using VSB video signal can be comfortabl transferred and it provides almost same bandwidth a SSB modulation.

Advantage	• Highly efficient. • Reduction in bandwidth when compared to AM and DSB-SC waves. • Filter design is easy, since high accuracy is not needed. • Low frequency components transmission is possible. • Good phase characteristics.
Drawback	• More bandwidth compared to SSB-SC technique. • Demodulation is complex.
Application	• Used in TV, Video transmission, Radio navigation and military communication.

Generation of VSB


m(t)
Product Modulator
DSBSC wave
Side Band Shaping Filter
VSBSC wave
$c(t) = A_c \cos(2\pi f_c t)$
Local Oscillator

- ➢ In this method first we generate DSBSC wave wit the help of the product modulator.
- ➢ Then apply this DSBSC wave as an input o sideband shaping filter to produce the VSB-SC wave.
- ➢ The output of the product modulator

$$p(t) = A_c \cos(2\pi f_c t) m(t)$$

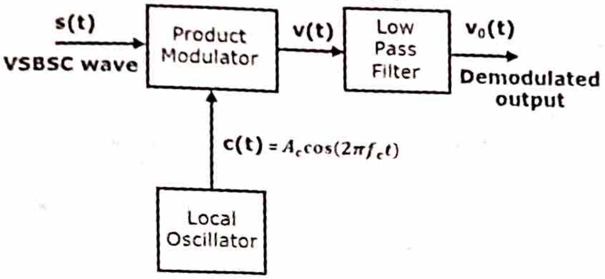
$$P(f) = \frac{A_c}{2}\left[m(f - f_c) + m(f + f_c)\right] \text{ (DSB-SC)}$$

- ➢ Output of the filter
  S(t) = P(f).H(f)

$$s(f) = \frac{A_c}{2}\left[m(f - f_c) + m(f + f_c)\right]H(f) \text{ (VSB-SC)}$$

i. Analog multiplier **ii.** Envelope detector

■ Demodulation of VSB-SC



- **Synchronous detector or coherent detector**
- ➢ Demodulation of VSB-SC wave is similar to the demodulation of DSB-SC
- ➢ The message signal can be extracted from VSB-SC wave by multiplying it with a carrier (having same phase and frequency as like used in VSB-SC modulation)
- ➢ The resulting signal is passed through a low pass filter.
- ➢ The output of this filter is the desired message signal.
- ➢ The output of the product modulator

$$v(t) = A_c \cos(2\pi f_c t) s(t)$$

$$v(f) = \frac{A_c}{2}\left[S(f - f_c) + S(f + f_c)\right]$$

- ➢ The output of the filter.

$$v_0(f) = \frac{A_c^2}{4} M(f)\left[H(f - f_c) + H(f + f_c)\right]$$

- **Different AM System at $\mu_a = 1$:**

System	P_t	P_s (Saved power)	% power saving	BW	SNR
AM-DSB/FC	$P_C\left(1+\frac{\mu_a^2}{2}\right)$	-	-	$2\omega_m$	max
AM-DSB/SC	$P_C\frac{\mu_a^2}{2}$	P_C	67%	$2\omega_m$	low
AM-SSB/FC	$P_C\left(1+\frac{\mu_a^2}{4}\right)$	$P_C\frac{\mu_a^2}{4}$	16%	ω_m	high
AM-SSB/SC	$P_C\frac{\mu_a^2}{4}$	$P_C\left(1+\frac{\mu_a^2}{4}\right)$	83%	ω_m	min

- **Commercial names of different modulation techniques**

AM(DSB-FC)	→	A3E ✓
SSB-FC	→	H3E
SSB-SC	→	J3E
SSB with reduced carrier	→	R3E
ISB	→	B8E
VSB	→	C3F ✓

❑ Angle Modulation

- ➢ Angle modulation in which the angle of carrier wave vary according to modulating signal.
- ➢ Angle modulation is non-linear modulation while AM is linear modulation.
- ➢ Angle modulation has constant power
- ➢ An important features of angle modulation is that it can provide better discrimination against noise and interference than AM.
- ➢ Angle modulation has two types-
  i. Frequency modulation
  ii. Phase modulation

■ Frequency Modulation (FM)

The frequency of the carrier wave is varied in a accordance with the instantaneous amplitude of the modulating signal.

Message signal- $m(t) = A_m \cos(\omega_m t + \phi_m)$

Carrier signal- $c(t) = A_c \cos(\omega_c t + \phi_c)$

- ➢ $S_{FM}(t) = A_C \cos[2\pi f_c t + 2\pi k_f \int m(t)dt]$
- ➢ $S_{FM} = A_z \cos\left[2\pi f_c t + \frac{\delta_f}{f_m}\sin\omega_m t\right]$
- ➢ Modulation index (μ_f) = $\frac{\text{Frequency deviation}}{\text{modulating frequency}}$

$$\boxed{\mu_f = \frac{\Delta f}{f_m} = \frac{k_f A_m}{f_m}}$$

- **Maximum Frequency deviation**
- ➢ It represents maximum deviation of the instantaneous frequency of the FM signal from the carrier frequency (f_c)
  $\delta_{FM} = k_f.A_m$
- ➢ δ_{FM} is independent of modulating signal frequency.

Narrow band FM (NBFM)	Wide band FM (WBFM)
• $\mu_f \le 1$	• $\mu_f > 1$
$\boxed{S_{NBFM}(t) = A_c \cos 2\pi f_c t - \frac{A_c\mu_f}{2}\cos 2\pi(f_c - f_m)t + \frac{A_c\mu_f}{2}\cos 2\pi(f_c + f_m)t}$	$\boxed{S_{WBFM} = A_c \sum_{n=-\infty}^{\infty} J_n(\mu_f)\cos 2\pi(f_c + nf_m)t}$
• $BW_{NBFM} = 2f_m$	• $BW_{WBFM} = \infty$
• Carrier power $\boxed{P_c = \frac{A_c^2}{2R}}$ • Total power $\boxed{P_t = \frac{A_c^2}{2R}\left[1 + \frac{\mu_f^2}{2}\right]}$	• Carrier power $\boxed{P_c = \frac{A_c^2 J_0^2(\mu_f)}{2R}}$ • Total power $\boxed{P_t = \frac{A_c^2}{2R}}$
• Single tone expression of AM and NBFM will be same, except 180^0	• WBFM contains carrier frequency component and

phase shift at LSB frequency component. - Bandwidth, transmitted power and the magnitude spectrum of AM and NBFM will be almost same. - AM preferred over NBFM.	infinite number of USB and LSB frequency component. - For WBFM most of the strength will be retained by lower order sideband frequency component and are said to be significant sideband.

Note: $\boxed{n = \mu + 1}$

Where, n = number of sideband

μ = Modulation index

➢ Carrier swing = $2\Delta f = f_{i(max)} - f_{i(min)}$

➢ Transmission Bandwidth-

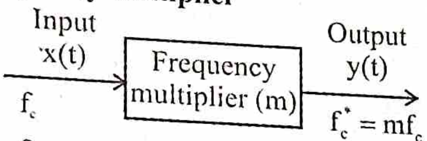
$$(BW)_{T(FM)} \approx 2(\Delta f + f_m) = (\mu_f + 1)2f_m$$

$$= 2\Delta f\left(1 + \frac{1}{\mu_f}\right) \text{\{Carson's bandwidth rule\}}$$

➢ Total power is same as carrier signal power before modulation.

➢ For multitone modulation, deviation ratio is inversely proportional to message signal frequency.

- **Frequency multiplier**

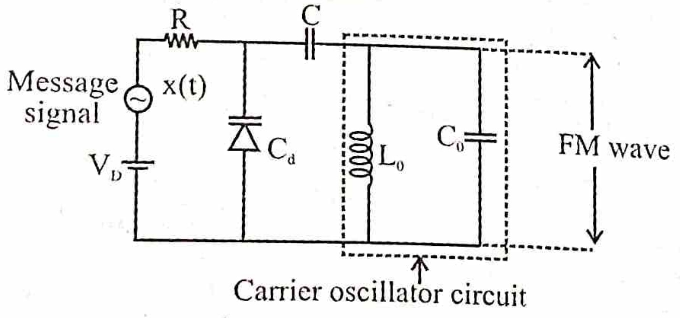


f_c	$f_c^* = mf_c$
β	$\beta^* = m\beta$
δ_{FM}	$\delta_{FM}^* = m\delta_{FM}$
f_m	$f_m^* = f_m$
B.W.	BW* = mB.W

Generation of FM wave-

i. Varactor diode modulator
ii. Reactance modulator } direct method
iii. Armstrong modulator - indirect method

- **Varactor diode modulator**



➢ Capacitance of varactor diode $C_d = \frac{k}{\sqrt{V_D}}$

➢ Voltage across varactor diode $V_D = V_0 + x(t)$

➢ Frequency carrier of oscillator $f_c = \frac{1}{\sqrt{L_0 C_0}}$ (If message signal is absent)

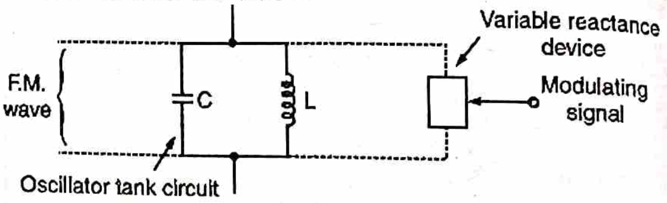
➢ If message signal is present then equivalent capacitance $C_{eq} = C_d + C_0$

➢ Instantaneous frequency $(f_i) = \frac{1}{\sqrt{L_0(C_0 + C_d)}}$

$$f_i = \frac{1}{\sqrt{L_0\left(C_0 + k\left[V_0 + x(t)\right]^{-\frac{1}{2}}\right)}}$$

➢ The instantaneous frequency (f_i) of FM signal depend V_D which in turns depends upon the value of message signal, x(t).

- **Reactance Modulator**



➢ A transistor of FET operated as a variable reactance (Inductive or capacitive) device.

➢ Voltage across resistance R,

$$\boxed{V_g = V_R = \frac{x(t)R}{R - JX_C}}$$

➢ For JFET $I_D = g_m \times V_g = \frac{g_m x(t)R}{R - JX_c}$

➢ Input impedance between terminal I and I' -

$$Z = \frac{1}{g_m}\left(1 - \frac{JX_c}{R}\right)$$

If $X_c >> R$

Then, $Z = \frac{-JX_c}{g_m R}$ (capacitive nature)

$$X_{eq} = Z = \frac{X_c}{g_m R} = \frac{1}{2\pi f g_m RC}$$

$$C_{eq} = g_m RC$$

➢ The value of C_{eq} and V_g change accordance to g_m.

➢ Reactance modulator circuit is used at the place of capacitor C in LC oscillator.

➢ So, C_{eq} change with the value of modulating signal and the oscillator frequency change also (it is the f_m signal).

➢ Carrier frequency drift because the instability of frequency.

➢ AFC (Automatic Frequency Control) is used to constant the carrier frequency.

➢ The DC voltage (generated by discriminator) stop the frequency variation of LC oscillator.

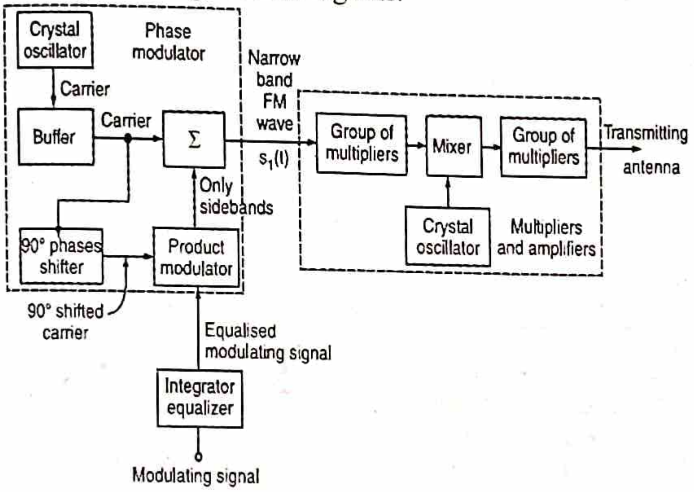
➢ Modulation index $\mu_f << 1$ in Armstrong modulator.

➢ Varactor diode modulator used in automatic frequency control, remote tuning and FM and PM generation.

Advantage	- Low cast - Simplicity of the modulators.
disadvantage	- Not easy to get high order of stability in carrier signal. - Used LC oscillator for carrier generation which is controlled by message signal due to this region direct method is not used for broadcast application. - The non-linearity of the varactor diode produces a frequency variation. - Due to harmonics of the message signal FM signal is distorted.

- **Armstrong Modulator**

➢ Major advantage of Armstrong method is, it capable of producing WBFM signals.


Crystal oscillator
Phase modulator
Carrier
Buffer
Carrier
Σ
Narrow band FM wave
$s_1(t)$
Only sidebands
90° phases shifter
Product modulator
90° shifted carrier
Equalised modulating signal
Integrator equalizer
Modulating signal
Group of multipliers
Mixer
Group of multipliers
Transmitting antenna
Crystal oscillator
Multipliers and amplifiers

➢ FM wave obtained through phase modulation.

➢ A crystal oscillator can be used.

➢ Armstrong system can be divided into two parts Part I and Part II

➢ Part I- generate a narrow band FM wave using a phase modulator

➢ Part II- use the frequency multipliers and mixer to obtain the required values of frequency deviation, carrier and modulation index

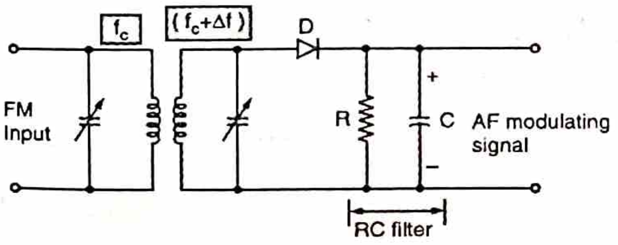
➢ Narrowband FM wave

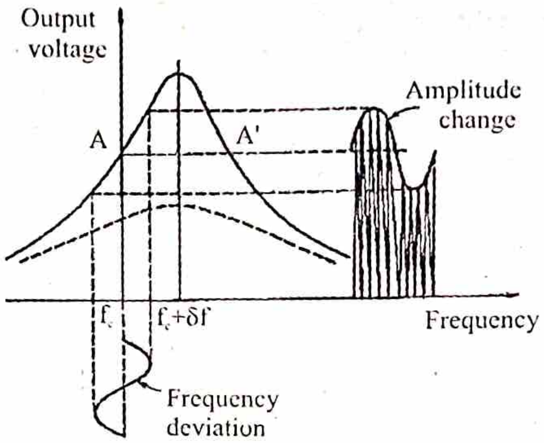
$$s_1(t) = A_{c1}\cos(2\pi f_1 t) - 2\pi k_1 A_{c1}\sin(2\pi f_1 t)\int_0^t x(t)dt$$

■ Demodulation of FM wave

• Frequency discriminator

- **Slope detector**


f_c
$(f_c+\Delta f)$
D
FM Input
R
+
C
−
AF modulating signal
RC filter



➢ Output voltage of tank circuit depends on the frequency deviation of input FM signal

➢ Identical to the AM diode detector

- **Drawback**

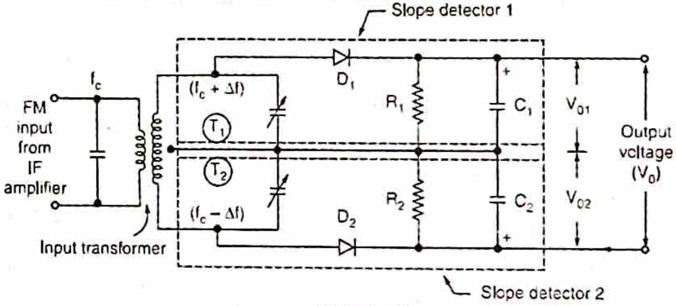
➢ It is an inefficient system

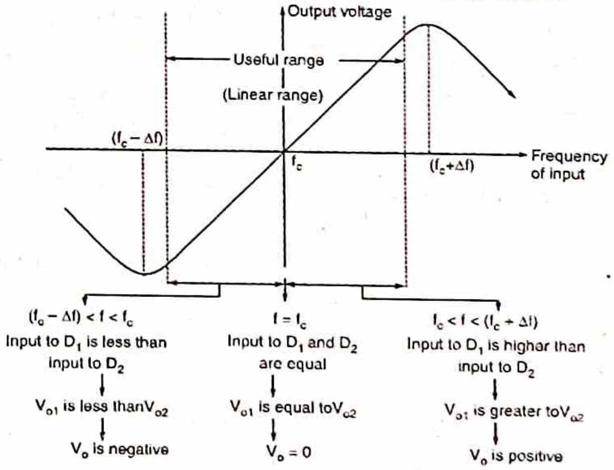
➢ Linear only over a limited frequency range.

➢ Difficult to set the primary and secondary winding of transformer at slightly different frequency.

➢ To overcome all the limitation of simple slope detector is use

• Balance slope detector


Slope detector 1
f_c
FM input from IF amplifier
$(f_c+\Delta f)$
T_1
T_2
$(f_c-\Delta f)$
Input transformer
D_1
D_2
R_1
R_2
C_1
C_2
V_{01}
V_{02}
Output voltage (V_0)
Slope detector 2



➢ It consists two slope detector circuits.

➢ The input voltages to the two slope detectors are 180^0 out of phase.

➢ It consists three number of tank circuit (tuned circuit)

➢ The characteristics of balanced slope detector is called as the 'S' shape characteristics

- **Advantage**

➢ More efficient than simple slope detector.

➢ Better linearity the simple slope detector.

- **Drawbacks**

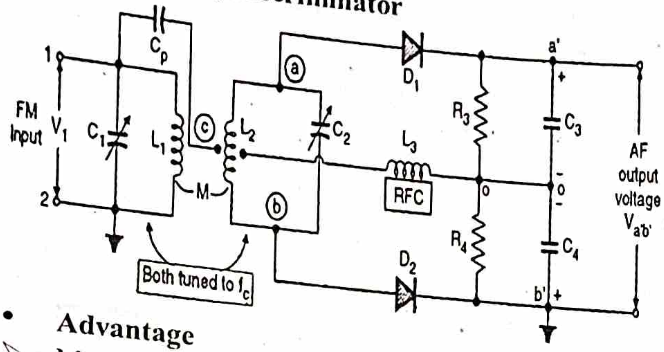
➢ Even though linearity is good it is not good enough.

➢ Difficult to tuned, since the three tuned circuits are work at different frequency

➢ Amplitude limiting is not provided

■ Phase discriminator

- **Foster seeley discriminator**



- **Advantage**

➢ More easily to tuned than the balanced slope detector as there are only two tuned circuit are used and tuned at the same frequency.

➢ Better linearity as compared to balanced slope detector.

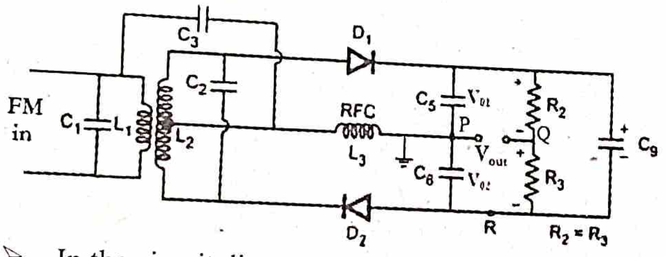
- **Drawback**

➢ Does not provide amplitude limiting.

➢. In the presence of noise or any other amplitude variation, the demodulator produces errors.

Note: It is used in satellite station.

- **Ratio detector**



➢ In the circuit diagram the direction of the diode D_2 is reverse.

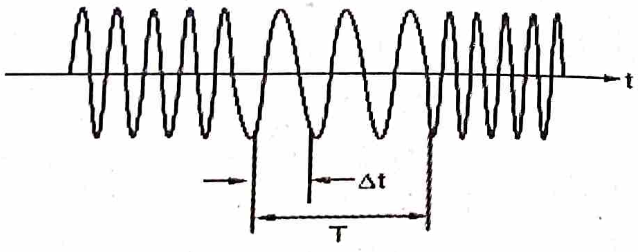
➢ A large value of capacitor has been included, at last in this circuit.

➢ The output is taken somewhere else.

➢ No need of amplitude limiter

➢ Output of ratio detector = $\dfrac{\text{output of foster seeley discrimination}}{2}$

- **Zero cross detector**



➢ Operates on the principle that the instantaneous frequency of FM signal is approximately given as

$$\boxed{f_i = \frac{1}{2\Delta t}}$$

➢ Δt is the time different between adjacent zero cross over point of the FM wave.

➢ The time (T) is selected such that is satisfied the following two conditions-

(i) $\boxed{T < \frac{1}{W}}$

W = Bandwidth of message signal

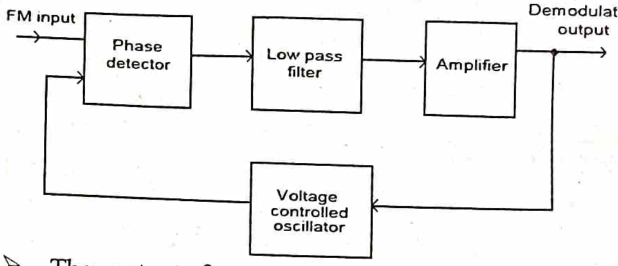
(ii) $\boxed{T > \frac{1}{f_c}}$

f_c = carrier frequency of AM wave

Linear relation between input frequency (f_i) and message signal x(t)

$$\boxed{f_i = f_c + k_f x(t)}$$

- **PLL detector (Indirect method)**



➢ The output frequency of VCO is equal to the frequency of unmodulated carrier.

➢ The phase detector generates voltage proportional to difference between FM signal & VCO output.

➢ The output of phase detector passes through LPF & amplifier.

➢ Hence frequency connection is not required at VCO, as it is done at transmitter.

➢ PLL system is close loop system design to locked output frequency and phase to the frequency & phase of input signal.

PLL have three stage-

i. **Free-running**

➢ If $V_C = 0$, VCO is free-running mode i.e. voltage control oscillator (VCO), oscillate with frequency (f_0).

ii. **Capture**

➢ If, $V_c \neq 0$ i.e. apply some voltage of VCO, the VCO frequency with changes from f_0 to f.

$f = f_0 + k_f.V_c$

Where, k_f = voltage sensitivity

➢ VCO frequency (f) change in such a way to reduce the difference between f_i & f_0. This action is called capturing & VCO is said to be capture mode.

iii. **Locking or Tracking**

➢ If $f_i = f_0$, the VCO is said to be locked/tracking & VCO is said to locked mode.

Note :

- ➢ Lock range > Capture range
- ➢ $\boxed{f_0 = \frac{0.25}{R_T . C_T}}$

Where, C_T = External capacitor,
f_0 = Free running frequency
R_T = External resistance

- ➢ Frequency of voltage conversion factor (K)

$$K = \frac{\Delta f_0}{\Delta V_c} = \frac{8 f_0}{V_{cc}}$$

- ➢ Deviation of the lock-in range (Δf_L)

$$\Delta f_L = \frac{\pm 7.8 f_0}{2 V_{cc}}$$

- **Advantage-**
- ➢ No need of tuned circuit
- ➢ Simple circuit that can be implemented in integrated circuit.

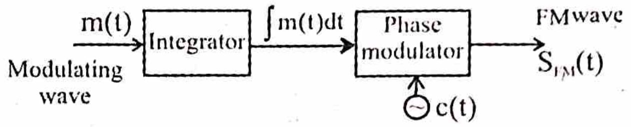
Phase modulation (PM)

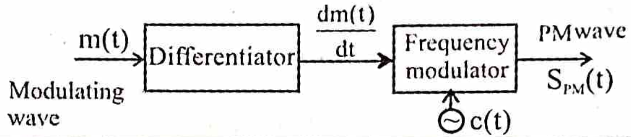
- ➢ The phase of the carrier wave is varied in accordance with the instantaneous amplitude of the modulation.
- ➢ For single tone modulation, deviation ratio is independent of message signal frequency.
- ➢ $S_{PM}(t) = A_c \cos\left[2\pi f_c t + \Delta\phi \cos(2\pi f_m t)\right]$
- ➢ Modulation index, $\mu_P = \Delta\phi = k_p . A_m$
- ➢ Maximum frequency deviation $\Delta f = k_p$
- ➢ Phase deviation

$$\boxed{(\Delta\phi)_{max} = \max\left[\phi(t)\right] = \max\left[k_p m(t)\right] = k_p . A_m}$$

- ➢ Phase modulation peak frequency deviation depends on A_m and f_m.

Equivalence Between FM and PM





PM	FM
$\mu_p = k_p . A_m$	$\mu_f = \frac{k_f . A_m}{f_m}$
$\Delta f = k_p . A_m . f_m$	$\Delta f = k_f . A_m$

	FM	AM
Frequency range	88 MHz-108MHz	550 kHz-1650 kHz
Bandwidth	200 kHz	10 kHz
Maximum frequency deviation	75 kHz (for broad costing of FM) 25 kHz (for TV broad costing)	------
Intermediate frequency (IF)	10.7 MHz	455 kHz

Parameters	**P.M.**	**F.M.**	**Single Tone PM**	**Single Tone FM**
Message	m(t)	m(t)	$A_m \cos 2\pi f_m t$	$A_m \cos 2\pi f_m t$
Instantaneous frequency	$f_i = f_c + \frac{k_p}{2\pi}\frac{d}{dt} m(t)$	$f_i = f_c + k_t m(t)$	$f_i = f_c - k_p A_m f_m \sin 2\pi f_m t$	$f_i = f_c + k_f A_m \cos 2\pi f_m t$
Instantaneous phase	$\phi_i(t) = \theta_i(t) + k_f m(t)$	$\phi_i(t) = \theta_i(t) + k_f \int m(t) dt$	$\phi_i(t) = 2\pi f_c t + k_f A_m \cos 2\pi f_m t$	$2\pi f_c t + k_f$ $\left(2\pi f_c t + \frac{k_f A_m}{f_m} \sin 2\pi f_m t\right)$
Modulation index	$\mu_p = k_p \max[m(t)]$	$\mu_f = \frac{k_f \max[m(t)]}{\text{Bandwidth}}$	$\mu_p = A_m K_p$	$\mu_f = \frac{A_m k_t}{f_m}$
Frequency deviation	$\Delta f = \frac{k_p}{2\pi}\frac{d}{dt} m(t)$	$\Delta f = k_f m(t)$	$\Delta f = k_p A_m f_m \sin 2\pi f_m t$	$\Delta f = k_f A_m \cos 2\pi f_m t$

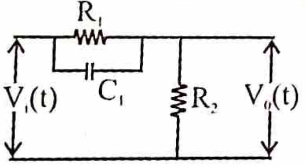
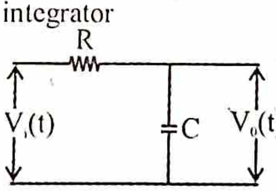
- **Comparison between FM & PM**

Frequency modulation	**Phase modulation**
$A_c \cos(\omega_c t + \beta_t \sin \omega_m t)$	$A_c \cos\left[\omega_c t + \beta_p \sin \omega_m t\right]$
$\boxed{\Delta f = k_f . V_m}$ & $\boxed{\beta = \frac{k_f V_m}{f_m}}$	$\boxed{\Delta f = k_p V_m f_m}$, & $\boxed{\beta = k_p V_m}$
Noise immunity better than AM & PM	Noise immunity better than AM but worst than FM
SNR is better than PM	SNR is worst than FM
FM is widely used in good quality music system	PM is used some mobile system

- **Comparison between AM and FM**

Amplitude modulation	Frequency modulation
Transmitter power is depends on modulation index	Transmitter power remains constant & independent of modulation index
Carrier & one side band are useless	All transmitted component are useless
AM receiver are not to immune noise	FM receiver are noise immune capability
AM bandwidth is constant and independent from modulation index. $\boxed{BW = 2f_m}$	FM bandwidth depends on the modulation index $BW = 2f_m(\mu_f + 1)$
AM have two side band	FM have infinite sideband
Bandwidth is much smaller than FM	Bandwidth is large than AM
Net possible to operate more channel on same frequency.	It is possible to operate more than one channel one frequency.
Used in ground wave & sky wave propagation so cover the large area of operation.	Used in space wave propagation so, are of operation is limit.

- **Comparison of Pre-emphasis and De-emphasis**

Pre-emphasis	De-emphasis
In pre-emphasis technique which is used to increase the signal power at high audio frequency	It is just reverse action of pre-emphasis at the discriminator output back the original signal.
It is used before frequency modulator or at transmitter.	It is used after FM demodulator and before base band filter.
It behave as a HPF (high pass filter) or differentiator at I.F. (2.1 kHz to 15 kHz).  	It is behave as a LPF (low pass filter) or integrator 

- **Transmitter**

➢ Transmitter not only performs the modulation process but also raises the power level of a modulated signal to the desired for effective radiation.

➢ Transmitter are two types-

(i) Low level modulator (ii) High level modulator

Low level modulator	High level modulator
It is also called base modulator.	It is also called collector modulator.
In low level modulation, lower power level modulate and then signal is amplified by using class-B power amplifier.	It is used class-C power amplifier which amplifies only the carrier frequency.
It is linear amplifier.	It have good linearity.
It is used in initial stage of amplification.	It is used in final stage of amplification.
It modulation circuitry simple & handle low power	It modulation circuitry complex and handle high power.
It is used only for laboratory purpose.	It is used in practical AM systems.
Square low diode modulator & switching modulator with the example of low level modulation	Collector modulator method are the example of high level modulation.

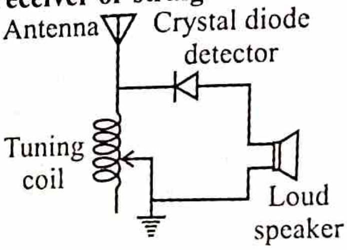
- **T.V. Transmission**

➢ Picture signal-5.75MHz, sound signal -0.25MHz

➢ Maximum $(f_m) = 5kHz$

■ Radio Receiver

1. Crystal receiver or straight receiver

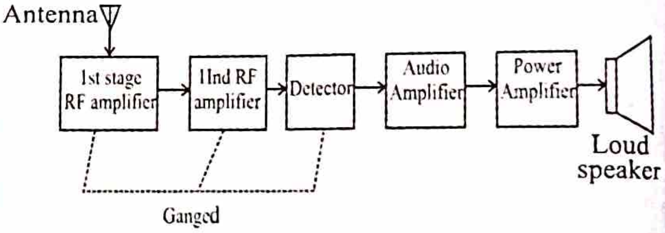


➢ Crystal receiver circuit is simple.

➢ Poor selectivity and sensitivity.

➢ Low output at receiver due to absence of amplifier.

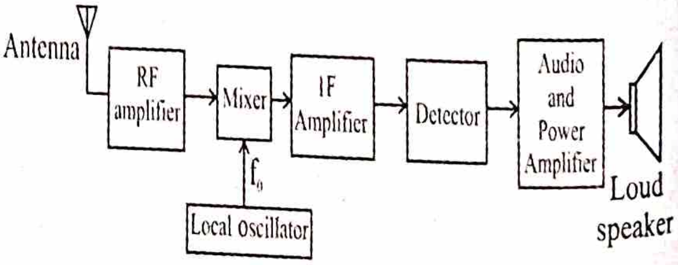
2. Tuned Radio Frequency (TRF) Receiver-



➢ It is used only as a fixed frequency receiver

Advantage	disadvantage
TRF receiver circuit is simple.	Instability
Sensitivity-high	Bandwidth variation over the tuning range.
Easy alignment at transmission range (535 kHz-1640 kHz).	Insufficient adjacent frequency rejection.
No problem of tracking & alignment.	At high frequency, performance of TRF is poor.

3. Super Heterodyne Radio Receiver-(SHRR)-



- **SHRR Performs in the following stages**

1. **RF section & characteristics**

- ➢ It is a class-C tuned voltage amplifier.
- ➢ It is reject the image signal.
- ➢ RF amplifier has larger gain therefore better sensitivity and improved SNR.
- ➢ RF amplifier improve image frequency rejection of adjacent un-wanted signal therefore better selectivity.
- ➢ It provide better coupling of receiver to the antenna.

2. **Mixer**

- ➢ It is non-linear device and provides sum & difference frequency.

IF = Intermediate frequency = $f_{LO} - f_s$

Where, f_{LO} = Local oscillator frequency

f_s = Incoming signal frequency (RF)

3. **Local oscillator**

2ctu 3×10^8

- ➢ f_{LO} is generated by local oscillator
- ➢ Local oscillator is LC- oscillator
- ➢ In SHRR, tuning achieved by local oscillator.
- ➢ $f_{LO} > f_s$

  AM = 550 kHz- 1650 kHz
- ➢ If $f_{LO} > f_s$ then, f_{LO} = 1005 kHz-2105 kHz
- ➢ If $f_s > f_{LO}$

$$\boxed{\frac{C_{max}}{C_{min}} = \frac{158}{1}}$$

4. **IF amplifier**

- ➢ IF-amplifier uses standard tuned amplifier & provides most of the receiver gain.
- ➢ Very high IF has poor selectivity & very good image frequency rejection.
- ➢ The IF-amplifier is SHRR is two stage of single tuned amplifier.

Note :

- ➢ Double spotting in SHRR caused by poor front end rejection.
- ➢ Double spotting is also called adjacent channel selectivity.

- **Image frequency rejection**

$\boxed{f_{si} = f_{LO} + f_i}$ $\boxed{f_{LO} = f_s + f_i}$ $\boxed{f_{si} = f_s + 2f_i}$

$F_{LO} \rightarrow$ Local oscillator frequency

$F_s \rightarrow$ Signal frequency , $F_{si} \rightarrow$ Image frequency

- **Rejection-** $\alpha = \sqrt{1+Q^2P^2}$, $P = \frac{f_{si}}{f_s} - \frac{f_s}{f_{si}}$

- ➢ They incoming signal frequencies are converted into a fixed frequency called the intermediate frequency (IF) by the mixture.
- ➢ The IF of 455kHz is used in commercial radio receivers.
- ➢ The IF is demodulated to recover the message signal.
- ➢ The modulated message signal is passed through the audio amplifier are power amplifier to achieved the desired signal.

- **Sensitivity-** Ability to amplify weak signals.
- **Selectivity-** Ability to reject unwanted signals.
- **Fidelity-** Ability to reproduce all the frequency components, which are present in original signal.
- **Automatic gain control-** The automatic gain control (AGC) within a superheat radio enables the gain of the receiver to be controlled to level the audio output.

☐ Pulse modulation-

- **Sampling theorem-** The sampling theorem specifies the minimum-sampling rate at which a continuous-time signal needs to be uniformly sampled so that the original signal can be completely recovered or reconstructed by these sample alone.

$f_s \geq 2f_m$, $f_{s_{min}} = 2f_m$

$$T_s \leq \frac{1}{2f_m}$$

- **Sampling period (T_s)-** Time between two samples.
- **Sampling rate** = $\frac{1}{\text{sampling period}} = \frac{1}{T_s}$
- **Type of sampling technique or ideal sampling**

i. Instantaneous sampling
ii. Flat-top sampling
iii. Natural sample sampling

Instantaneous sampling	**Flat-top sampling**	**Natural sample sampling**
It is also known as impulse train sampling	It is also known as practical sampling	It is also known as practical sampling
In this method, the sampling signal is periodic impulse train.	In this method, the sampling signal is a pulse train	In this method, the sampling signal is pulse train
In this method, the area of ends impulse in the sampled signal is equal to the instantaneous value of the input signal.	The top of each pulse in the sampled signal remain constant & equal to the instantaneous value of the input signal at the star of the samples.	In this method, the top of each pulse in the sampled signal retains the shape of the input signal during pulse interval.
It is not used in practical due to zero width & not practically possible to generate.	A flat-top sample pulse is generated by passing the instantaneous sampled signal through a monostable M.V.	In this method SNR ratio is not constant.

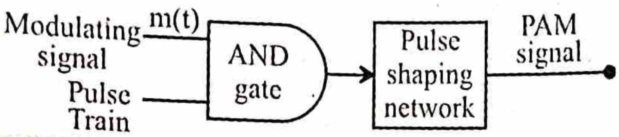
Pulse Amplitude modulation (PAM)-

- ➢ The amplitude of pulses varies with the instantaneous sample values of a message signal.

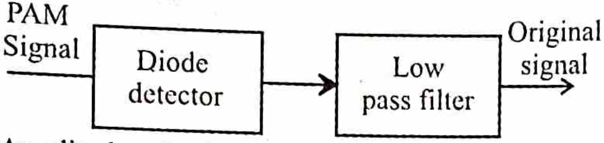
There are two types of PAM-

i. Double polarity PAM
ii. Single polarity PAM.

- **Generation**


Modulating signal
m(t)
Pulse Train
AND gate
Pulse shaping network
PAM signal

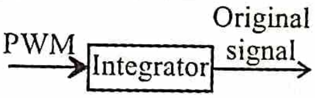
- **Demodulation**


PAM Signal
Diode detector
Low pass filter
Original signal

- ➢ Amplitude of pulse of PAM wave, is not constant (but in PPM and PWM amplitude is constant)
- ➢ More noise effect
- ➢ Used in instrumentation system, A/D converter and generation of PCM.

Pulse width Modulation (PWM)

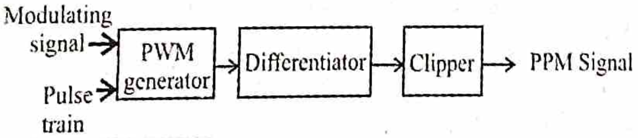
- ➢ The sample of message signal are used to vary the duration of individual pulses.
- **Generation-** PWM can be generated by 555 timer in monostable multivibrator mode.
- **Demodulation-**


PWM
Integrator
Original signal

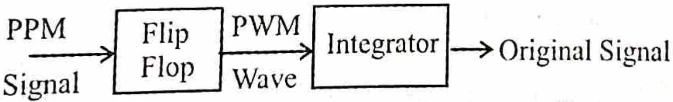
- ➢ No needs of synchronization between transmitter and receivers.
- ➢ Pulse widths are different

Pulse Position Modulation(PPM)

- ➢ The position of pulse relative to the position of unmodulated pulse is varied in accordance with the message signal.
- **Generation**


Modulating signal
Pulse train
PWM generator
Differentiator
Clipper
PPM Signal

- **Demodulation**


PPM Signal
Flip Flop
PWM Wave
Integrator
Original Signal

- ➢ Constant transmitter power and pulse amplitude
- ➢ Synchronization is needed between receiver and transmitter.
- ➢ PPM System is a noise free system

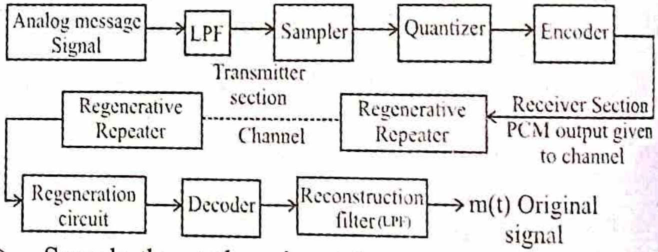
	B.W	Power efficiency (SNR)	Complexity
PAM	Less	Lowest	Lowest
PWM	High	Moderate	Moderate
PPM	High	Highest	Highest

- **Comparison of PAM, PPM and PWM**

PAM	PDM or PWM	PPM
Amplitude of the pulse is proportional to amplitude of modulating signal.	Width of the pulse is proportional to amplitude of modulating signal.	The relative position of the pulse is proportional to the amplitude of modulating signal.
The bandwidth of the transmission channel depends on width of the pulse.	Bandwidth of transmission channel depends on rise time of the pulse.	Bandwidth of transmission channel depends on rising time of the pulse.
The instantaneous power of the transmitter varies.	The instantaneous power of the transmitter varies	The instantaneous power of the transmitter varies
Noise interference is high and system is complex.	Noise interference is minimum.	Noise interference is minimum.
Similar to amplitude modulation.	Simple to implement similar to frequency modulation.	Simple to implement similar to phase modulation.

Pulse code modulation (PCM)-

- ➢ Pulse code modulation (PCM) is a method used to digitally represent sampled analog signal.
- ➢ Main process of PCM transmitter-sampling, quantizing and encoding and receiver - regeneration (cleaning and reshaping), decoding and filtering.


Analog message Signal
LPF
Sampler
Quantizer
Encoder
Transmitter section
Receiver Section
PCM output given to channel
Regenerative Repeater
Channel
Regenerative Repeater
Regeneration circuit
Decoder
Reconstruction filter (LPF)
m(t) Original signal

- ➢ Sample the analog signal then quantize it to convert into levels and encode it and then send it in the form of digital codes.
- ➢ If there is n bit quantizer and sampling rate is f_s then bit rate will be $R_b = n f_s$ bits/sec

For n-channel, $R_b = N.nf_s$

- ➢ $(B.W.)_{min} = \frac{R_b}{2} = \frac{nf_s}{2} = nf_m$

For n-channel, $BW = N.nf_m$

- ➢ Step size $(\Delta) = \frac{V_{max} - V_{min}}{L}$ $(L = 2^n)$
- ➢ Quantization noise power for uniform quantization $(N_q) = \frac{\Delta^2}{12}$

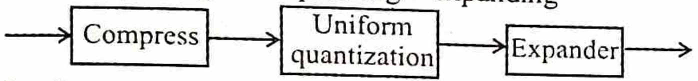
- Signal to noise ratio in dB $(SNR)_{db}$ = 1.8+6n(for sinusoidal signal)
- Signal to noise ratio in dB $(SNR)_{db}$ = 4.8+6n(for non-sinusoidal signal)
- Bit period = $\frac{\text{Sampling Period}}{\text{No. of bit}}$
- Sampling period $(T_s) = \frac{1}{2f_m}$
- For n-channel & synchronization 'a' number of bit are transmitted at the end then,

  $\boxed{R_b = (N.n + a) f_s}$
- Transmission bandwidth B_T = 1.544 MHz
- Ruggedness to channel noise and other interference.
- Efficient generation of the coded signal along the transmission path is possible.
- Security of information.
- Complex encoding and decoding.
- Long transmission bandwidth.

- **Non-uniform quantization**

- An audio signal is to be transmitted digitally for good fidelity we used PCM system with non-uniform quantization.
- Non-uniform quantization is practically achieved through a process called companding.

  Companding = compressing + expanding



- In companding method, the weak signals are amplified and strong signal are attenuated before apply them to uniform quantization this process is called compression and it is included at the PCM transmitter.
- At receiver exactly opposite is followed which is called expander.

Note: The use of non-uniform quantizer leads to increase in signal to noise ratio for signal level.

- **Type of companding**

- It is two types

i. μ– law companding
ii. A- law companding

μ-law companding	A-law companding
In μ-law companding the compression characteristics is continuous.	In A-law companding the compression characteristics is linear.
It is approximately linear path for smaller value of input signal level & logarithmic for high signal level.	It is also approximately linear for small signal level & logarithmic for high signal level.
The μ-law companding is used for speech and music signal.	A-low companding is also used for PCM telephone system in Europe.
It is also use for PCM telephone system is united state (USA).	A-law companding is also used for PCM telephone system in India.
Typical value of μ= 255	Typical value of A=87.6.

DPCM (Differential Pulse Code Modulation)

- In DPCM the difference amplitude between sample and previous sample is to be transmitted.
- The peak amplitude of transmitted value in reduce using DPCM.
- for given SNR, we can transmit at reduce bandwidth.
- DPCM is used for speech signal transmission.
- In DPCM, predictor filter is used.

Delta Modulation

- 1-bit DPCM is called modulation
- In delta modulation number of bit/sample is used one.
- In delta modulation the number of levels is used two.
- In delta modulation, bit rate is equal to the sampling rate.
- Demodulation of delta modulation achieved by integrator.
- Two types of error in delta modulation

i. Slope over distortion ii. Granular noise

Slope over distortion	Granular noise
Slope over load distortion is delta modulation when the rate of change of analog signal too large (or large dynamic range of input signal)	Granular noise occur when the modulating signal remain constant (or step size is too large)
It can be reduced by increasing the step size	It can be reduced by make the step size small.
To avoid slope over distortion $\frac{\Delta}{T_s} \geq \left\|\frac{dm(t)}{dt}\right\|_{max}$	Granular noise power $= \frac{\Delta^2}{3} W$
To take place over distortion $\frac{\Delta}{T_s} < \left\|\frac{dm(t)}{dt}\right\|_{max}$	

ADM (Adaption Delta Modulation)

- In ADM has variable step size.
- For small variation of signal (constant signal) ADM is used small step size so that granular noise.
- For large variation of signal ADM is used large step size so that slope over load distortion reduces.

Comparison between PCM, DPCM, DM and ADM

Parameters	PCM	DPCM	DM	ADM
No. of bits (n)	Either 4, 8 or 16 bits/sample *8 bits/sample is most common	n is greater than 1 and less than no. of bits in PCM system.	n = 1	n = 1
Feedback requirement	No	Yes	Yes	Yes
Step size (s)Δ	Fix	Fix	Fix	Variable
Complexity	Most complex circuit	Moderate complex circuit	Simple circuit	Simple circuit
Type of error	Mainly quantization error	Quantization error and granular noise effect	Both slope overland and granular noise error	Quantization error
Bandwidth (BW)	High B.W.	Moderate B.W.	Least B.W.	Least B.W.

FDM (Frequency Division Multiplexing)

- FDM is used for multiplexing continuous signal
- The entire frequency interval is divided into smaller frequency slots.
- Separate transmitter and receiver are required.
- More circuit complexity.
- Synchronization is not a problem.
- All signals are passed simultaneously through the channel.
- Crosstalk is more because different message signals are simultaneously applied.
- Here band-pass filters are used.
- The modulated signal spectrum may be separated by small guard band to avoid interference.
- The total bandwidth is divided to a set of frequency bands that do not overlap.
- The frequency bands are separated from one another by strips of unused frequencies called the guard bands to prevent overlapping of signals.
- The modulated signals are combined together using a multiplexer in the sending end.
- The combined signal is transmitted over the communication channel.
- At the receiving end, the individual signals are extracted from the combined signal by the demultiplexing process.

Advantage	• No dynamic coordination needed • Works also for analog signals
Disadvantage	• Waste of bandwidth (if traffic distributed unevenly) • Inflexible • Guard space

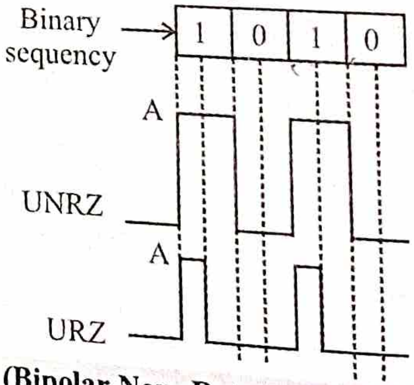
Time Division Multiplexing (TDM)

- In TDM, the signals are separated in time f_{out} mixed in frequency.
- In a TDM system each signal allotted in a frame and fixed time slot.
- In a TDM system non-essential frequency component of the modulating signal are remove by low pass filter (pre-aliasing filter)
- It has least circuit complexity.
- In TDM, synchronization is very much essential.
- It is immune to non-linearity in the channel as source of crosstalk.
- TDM is use when the data to be transmitted is fas changing and wideband width.
- In order to separate signal in a TDM system, it i necessary to used AND-gate.
- TDM is digital multiplexing technique and require transmission of data sample.
- In TDM system full channel available bandwidth can be used by each signal.

- **Line codes**
- Line coding is the process of converting digital data to digital signals.

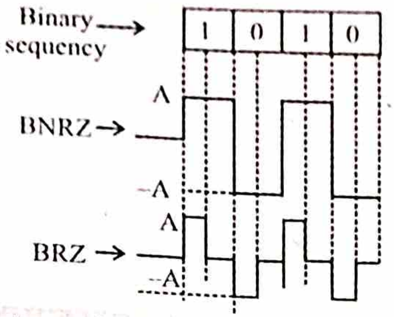
- **Types of line code**

1. **UNRZ (Unipolar Non-Return to Zero) codes**
   - A '1' is represented by positive pulse
   - A '0' is represented by no pulse.
2. **URZ (Unipolar Return to Zero) codes**
   - A '1' is represented by a positive pulse of half symbol width
   - A '0' is represented by no pulse.



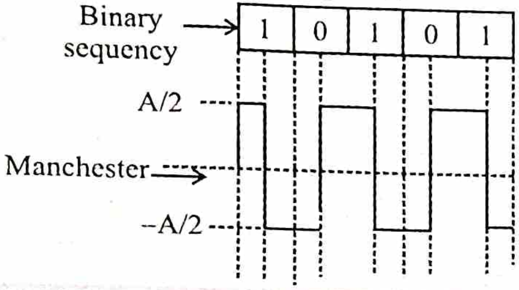
3. **BNRZ (Bipolar Non- Return to Zero) codes**
   - A '1' is represented by positive pulse.
   - A '0' is represented by negative pulse.
4. **BRZ (Bipolar Return Zero) Codes**
   - A '1' is represented by positive pulse of half symbo

- A '0' is represented by negative pulse of half symbol width.



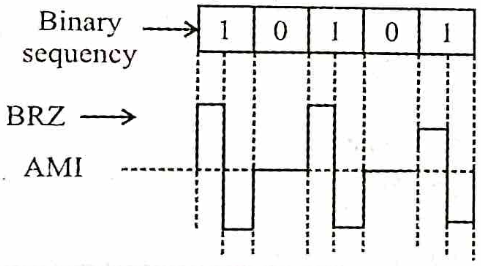
5. Manchester code (Split-Phase code)

- A '1' represented by a positive half-symbol width pulse followed by a negative half-symbol width pulse.
- A '0' represented by a negative half-symbol width pulse followed by a positive half-symbol width pulse.
- This code has a zero DC component.



6. BRZ-AMI (Binary Return to Zero- Alternative Mask inversion) Code

- A '1' is represented alternately by positive & negative pulse of half width.
- A '0' is represented by no pulse.



❑ Digital Modulation system

Amplitude shift keying (ASK)	• Amplitude of a high frequency carrier is varied in accordance with digital data (0 or 1). • 1→ presence of carrier • 0→ Absence of carrier • On-OFF signaling is used. • Less SNR, probability error (P_e) is high. • Lowest noise immunity • Transmission bandwidth $B_T = \frac{2}{T_b} = 2R_b$ • Spectral efficiency (e) = 0.5 bps/Hz • ASK modulation scheme is provide maximum probability of error.
Frequency shift keying (FSK)	• Frequency of carrier is varied in accordance with digital data (1or 0) • NRZ signaling is used. • Used in modem • Multiplexing is difficult • Transmission Bandwidth $B_T = 2R_b + (f_1 - f_2) \simeq 4R_b$ • In case of FSK P_e is less and SNR is high • Spectral efficiency (e) = 0.25 bps/Hz • FSK s demodulated by PPL • FSK used in telegraphy
Phase shift keying (PSK)	• Phase of high frequency carrier varied is accordance with digital data (1 or 0) • NRZ signaling is used. • Transmission Bandwidth $B_T = 2R_b$ • Probability of error is less. • SNR is high. • Best among all shift keying schemes • Spectral efficiency E=0.5 bps/ Hz

- **M-ary signaling**

- For M-ary PSK $B.W = \frac{2R_b}{\log_2 M}$
- Boud rate $= \frac{\text{Bit rate}}{\log_2 M}$

▪ **Binary amplitude shift keying (BASK)**

- $$s(t) = \begin{cases} A_c \cos 2\pi f_c t; & \text{for } 1(\text{High signal}) \\ 0; \quad ; & \text{for } 0(\text{Low level}) \end{cases}$$

- **Bandwidth of BASK**

$\boxed{B_T = 2R_b}$ (for NRZ pulse)

$\boxed{B_T = R_b(1+\alpha)}$ (for raised cosine)

- **Energy per bit,** $\boxed{E_b = \frac{A^2 T_b}{2}}$

▪ **Binary phase shift keying (BPSK)**

- $$s(t) = \begin{cases} A_c \cos 2\pi f_c t & ;\text{for } 1(\text{High signal}) \\ -A_c \cos 2\pi f_c t & ;\text{for } 0(\text{Low signal}) \end{cases}$$

- **Boud rate** $\boxed{R_s = \frac{R_b}{\log_2 m}}$

M-ary phase shift keying

M-ary	Bandwidth	....distance
BPSK	$2R_b$	$2\sqrt{E_b}$
4-ary PSK	R_b	$2\sqrt{E_b}$
8-ary PSK	$0.6R_b$	$1.32\sqrt{E_b}$
16-ary PSK	$R_b/2$	$0.78\sqrt{E_b}$

➢ Special efficiency $\boxed{\rho = \frac{\text{Bit rate }(-R_b)}{\text{Bandwidth }(B_T)}}$

Binary frequency shift keying (BFSK)

➢ $s_1(t) = A_c\cos(2\pi f_H t)$ bit = 1

➢ $s_2(t) = A_c\cos(2\pi f_L t)$ bit = 0

- **Bandwidth** $\boxed{B_T = 2R_b + f_H - f_L}$ (for NRZ pulse)
- **Energy per bit** $\left(E_b = \frac{A^2T_b}{2}\right)$
- **For orthogonal BFSK** $\boxed{\begin{matrix} f_H = mR_b \\ f_L = nR_b \end{matrix}}$
- **For non-coherent BFSK** $\boxed{f_H - f_L = \frac{nR_b}{2}}$
- **For coherent BFSK** $\boxed{B_T = \frac{2R_b}{N}}$

$$\boxed{f_H - f_L = nR_b}$$

Probability Error

- **For BASK system** $\boxed{P_e = Q\left(\sqrt{\frac{E_b}{2N_0}}\right)}$
- **For BPSK system** $\boxed{P_e = Q\left(\sqrt{\frac{E_b}{N_0}}\right)}$
- **For BFSK system** $\boxed{P_e = Q\left(\sqrt{\frac{E_b}{N_0}}\right)}$

Imperfect phase Synchronization

$$\boxed{P_e = Q\sqrt{\frac{2E_s}{N_0}\cos^2\phi}}$$

- **Imperfect bit synchronization**

$$\boxed{P_e = Q\left(\sqrt{\frac{2E_s}{N_0}}\left(1-\frac{2|\tau|}{T}\right)\right)}$$

- $\boxed{(P_e)_{BPSK} < (P_e)_{BFSK} < (P_e)_{BASK}}$

- **Comparison of various digital modulation system**

Modulation type	Bandwidth	Probability error (P_e)
Coherent ASK	$2R_b$	$Q\left(\sqrt{\frac{A_c^2T_b}{4N_0}}\right)$
Non-coherent ASK	$2R_b$	$\frac{1}{2}\exp\left(-\frac{A_c^2}{8N_0}\right)$
Coherent FSK	$2R_b+(f_1-f_2)$	$Q\left[\sqrt{\frac{A_c^2T_b}{2N_0}}\right]$
Non-coherent FSK	>2Rb	$\frac{1}{2}\exp\left(-\frac{A_c^2}{4N_0}\right)$
Coherent PSK	$2R_b$	$Q\left(\sqrt{\frac{A_c^2T_b}{N_0}}\right)$
Non-coherent PSK	$2R_b$	

Noise effect on various analog modulation system

Noise

External
- Atmospheric noise
- Solar noise
- Industrial noise

Internal
- Shot noise
- Resistor/Johnson/Thermal noise
- Flicker noise
- Transit time noise

➢ Johnson noise is also known as thermal noise, electrical noise or resistor noise.

➢ Shot noise- due to the random movement of electrons and holes.

➢ Transit time noise (high frequency noise) occur during transition.

➢ In electronic devices shot noise occurs due to discrete nature of current.

➢ Johnson noise is due to random motion of free charged particles in a resistance.

➢ White noise is random noise that has a flat spectral density.

➢ Flicker noise is also known as $\frac{1}{f}$ noise or pink noise.

➢ Flicker noise is a form of electronic noise that dominates at low frequencies or low frequency offsets from oscillators.

➢ The natural source of noise that give rise to noise are electronic storms, solar flares and radiation in space.

➢ The noise originating from the sun and outer space is known as extraterrestrial noise (solar cosmic noise).

➢ The sun radiates lots of noise.

➢ Cosmic noise comes from stars.

➢ It is uniformly distributed over entire sky.

- **Effect of noise on a baseband system**

➢ Signal to noise ratio of a baseband system

$$\boxed{(SNR)_b = \frac{P_R}{N_0.B}}$$

Where, P_R = Received signal power
N_0 = Noise spectral density
B = Bandwidth of message signal

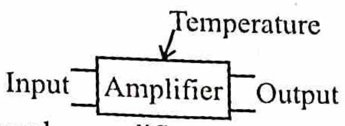
➢ High SNR is good for receiver and transmitter

- **Noise Figure**
- ➢ It is a ratio of SNR at input to SNR at output.

$$\boxed{F_N = \frac{SNR_{(i)}}{SNR_{(o)}} = \frac{P_i / P_{in}}{P_o / P_{on}} = \frac{P_i . P_{on}}{P_o . P_{in}}}$$

$$\boxed{F_N = \frac{P_{on}}{G.P_{in}}} \left(G = \frac{P_o}{P_i} \right)$$

- **Noise Temperature**
- ➢ It is a temperature , which generates noise power in system



- ➢ Noise power by amplifier.

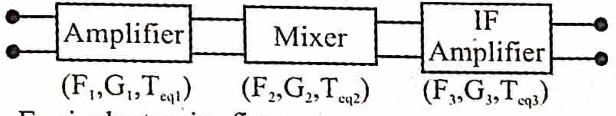
$$\boxed{P_{NA} = (F_N - 1) kT_0 B}$$

Where F_N = Noise figure
T_0 = Environment temperature
B = Bandwidth of message signal

- ➢ Noise power in terms of noise temperature.

$$T_{eq} = (F_N - 1) T_0$$

- ➢ Equivalent noise temperature and noise figure in cascaded communication system.



Equivalent noise figure

$$\boxed{F = F_1 + \frac{(F_2 - 1)}{G_1} + \frac{(F_3 - 1)}{G_1 G_2}}$$

Note: F_1, F_2 & F_3 would not be in terms of dB.

- **Equivalent noise temperature**

$$\boxed{T_{eq} = T_{eq_1} + \frac{T_{eq_2}}{G_1} + \frac{T_{eq_3}}{G_1 G_2}}$$

- **SNR of DSB-SC System**

$$\boxed{(SNR)_{o(DSB-SC)} = (SNR)_b = \frac{P_R}{N_0 B}}$$

- ➢ Output SNR of DSB-SC is same as base band system SNR.
- **SNR of SSB AM system**

$$\boxed{(SNR)_{0(SSB)} = (SNR)_{0(DSB-SC)} = (SNR)_b = \frac{P_R}{N_0 B}}$$

- ➢ Output SNR of SSB is same as SNR of DSB-SC system and baseband system.
- **Noise effect on AM system**

$$\boxed{(SNR)_{0(AM)} = \frac{A_c^2 \mu_a^2 P_n}{2 N_0 B}} \quad \boxed{(SNR)_{0(AM)} = \eta (SNR)_b}$$

$$\boxed{\eta = \frac{\mu_a^2 P_n}{\mu_a^2 P_n + 1}}$$

Where A_c = Carrier amplitude
μ_a = Modulation index
P_n = Normalized message signal power

- **Information theory**

$$I = \log_2 \left(\frac{1}{P} \right) \text{bits}, \quad I = \log_{10} \left(\frac{1}{P} \right) \text{decit or dit or Hartly}$$

$$I = ln \frac{1}{P} \text{ nat}$$

- ➢ The unit of information s bits, decit and Nat
- ➢ 1-decit = 1 Hartley = 3.32 bits = 2.5 Nat
- ➢ 1-Nat = 1.44 it = 0.4 decit
- **Entropy**
- ➢ It is measure of Un-certainity.
- ➢ It is also defined as average information per message.
- ➢ A given source will have maximum entropy if the message produced are equiprobable.

$$H = \sum_{i=1}^{m} P_i \log_2 \frac{1}{P_i} \text{ bits / symbol}$$

- **Rate of information (R)**
- ➢ If a message source generate message at the rate of 'r' message per second or symbol/sec. then

$$\boxed{R = r.H} \text{ bit/sec}$$

Where, H= entropy

- **Source coding**
- ➢ It is reduce the size of data
- ➢ Source coding in order to enhance the information rate
- **Code length**
- ➢ Average code word length per source symbol is represented by code length.

$$\boxed{\text{Code length } (L) = \sum_{i=1}^{i=m} P(x_i).nc}$$

Where, n = length of code for each message

- ➢ Code efficiency $(\eta) = \frac{L_{min}}{L}$
- ➢ Source encoder is said to be efficient when the coding efficiency (η) approaches unity.
- ➢ Redundancy = $1 - \eta$
- **Source coding theorem**
- ➢ $L \geq H(x)$

L_{min} = H(x) entropy

$$\boxed{\eta = \frac{L_{min}}{L} = \frac{H}{L}}$$

- **Channel capacity Theorem**

Case I : Channel capacity per symbol (Cs)

$$\boxed{C_s = Max I(x, y)} \text{ bit/symbol}$$

Case II : Channel capacity per second (C)

$$\boxed{C = C_s X_r} \text{ bit/sec.}$$

- **Capacity of an additive white Gaussion Noise channel**
- ➢ It is also called Shannon Hartley law
- ➢ Channel capacity- $C = B \log_2 \left(1 + \frac{S}{N} \right)$ bits / sec

- Channel capacity for a binary symmetric channel is $C_S = 1 + P\log_2 p + (1-P)\log_2(1-P)$ bits/symbol
- Channel capacity is maximum rate of information transmission.
- Channel coding theorem

$\boxed{C \geq R}$

Where, C= channel capacity (bit/sec)
R = Rate of information (bit/sec)

- If $\boxed{C \geq R}$ then probability of error decreases.
- If $\boxed{C<R}$, then probability of error increase.

- **Entropy coding**
- It is two types
(i) . Shanon- Fano coding (ii) Huffman-coding

Shanon-Fano coding	**Huffman-coding**
List the given probabilities in the decreasing order.	List the given probabilities in the decreasing order.
Partition the set into 2 parts that are close to equiprobable as possible and assign '0' to the upper set and '1' to the lower set.	Combine the given probabilities of 2 symbols having the lowest probability and reorder the resultant probabilities.
Continue this process until partition is not possible.	Start encoding with the last reduction and which consists of exactly 2 probabilities and assign '0' to the 1st digit in the code word for all the source symbols associated with 1st probability and assign '1' to the 2nd probabilities.
	Continue the process until 1st column is reached.

- **PDF (Probability Density or Probability Distribution Function)**

$$\rho_x(x) = \frac{d}{dx}F_x(x)$$

1. $\rho_x(x) \geq 0$
2. $\int_{-\infty}^{\infty} \rho_x(x)dx = 1$ Area under PDF is always 1
3. $F_x(x) = \int_{-\infty}^{x} \rho_x(x)dx$
4. $P\{x_1 \leq x \leq x_2\} = \int_{x_1}^{x_2} \rho_x(x)dx$

- **Means or First Moment:**

$$m_x = E[x] = \int_{-\infty}^{\infty} x\rho_x(x)dx$$

- **M.S.V. (Mean Square Value):**

$$E\left[x^2\right] = \int_{-\infty}^{\infty} x^2\rho_x(x)dx$$

- **Variance**

$$\sigma_x^2 = E\left[(x-m_x)^2\right] = \int_{-\infty}^{\infty}(x-m_x)^2\rho_x(x)dx$$

- **Properties of expectation operator**

1. $E[C] = C$
2. $E[CX] = CE[X]$
3. $E\left[\sum_i X_i\right] = \sum_i E[X_i]$
4. $E[x_1 + x_2 + x_3] = E[x_1] + E[x_2] + E[x_3]$

- **Commutative distribution function [F$_x$(n)]**
- The commulative distribution function is found by integrating the probability density function.

$$\boxed{f_x(n) = \int_{-\infty}^{x} f_x(n)dx}$$

- The probability density function is obtained by differentiate commulative distribution function.

$$f_x(n) = \frac{d}{dx}f_x(n)$$

- **Properties of commulative distribution function**
- Commulative distribution function of random variable 'X' may be defined as the probability that a random variable 'X' takes a value less than equal to x.

$$CDF = f_x(n) = \rho(x \leq n)$$

$$\boxed{0 \leq f_x(n) \leq}$$

- Commulative distributive function is non-decreasing function.

$$\boxed{0 \leq f_x(n) \leq 1} \quad f_x(\infty) = 0, \quad f_x(\infty) = 1$$

- **Mean value of random variables**
- Mean value of random variables E(n)

$$\underset{\text{Exceptation}}{E(n)} = \int_{-\infty}^{\infty} n.f_x(n).dx$$

Where, $f_x(n)$ = Probability density function
N= The value of random variables
X= Random variable

- **Mean square value of random variables [E(x)^2]**

$$\boxed{E(x^2) = \int_{-\infty}^{\infty} x^2 f_x(n)dx}$$

- Variance = mean square value – square of mean value
- Standard deviation [σn]

$$\sigma_n = \sqrt{\text{variance}} = \sqrt{E(x^2) - E(x)^2}$$

Note : In a communication system, a process for which, statistical average and time average are equal is called ergodic process.

$$E\left[x^2\right] \geq \left[E(x)^2\right]$$

Advance Communication

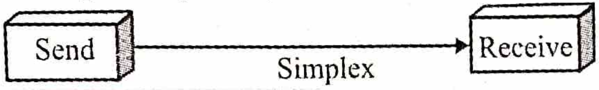
❑ Data Communication

■ Transmission Mode -

- ➢ Transferring data between two devices.

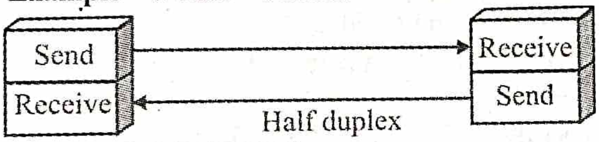
■ Simplex mode -

- ➢ Unidirectional communication.
- ➢ Sender can send the data but that sender cannot receive the data.
- ➢ It provides less performance than half duplex and full duplex.
- ➢ **Example** - Keyboard, Monitor.



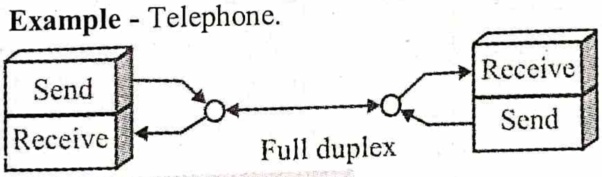
■ Half - duplex mode -

- ➢ Half duplex mode is a two-way directional communication but one direction at a time.
- ➢ In half duplex mode, sender can send the data and can receive the data but one direction at a time.
- ➢ Less performance than full duplex.
- ➢ **Example** - Walkie - Talkies.



■ Full-duplex mode -

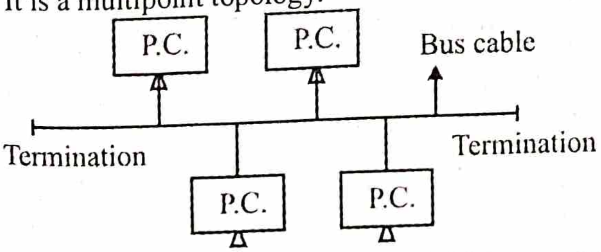
- ➢ Full duplex mode is a two-way directional communication simultaneously.
- ➢ In full duplex mode, sender can send the data and receive the data simultaneously.
- ➢ Better performance than simplex and half duplex mode.
- ➢ **Example** - Telephone.



❑ Network topology -

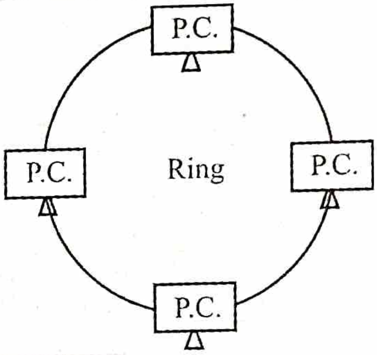
■ Bus topology -

- ➢ In bus topology, one long cable act as a single communication channel and all the devices are connected to this cable.
- ➢ Required only one cable.
- ➢ Easy to add/remove P.C. in this topology.
- ➢ Less expensive
- ➢ It is a multipoint topology.



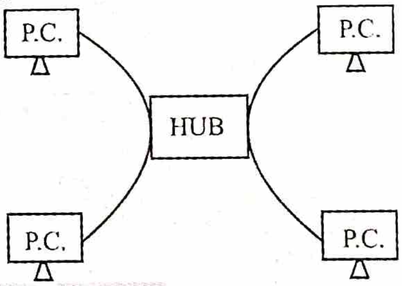
■ Ring topology -

- ➢ Each computer is strongly connected with adjacent computer.
- ➢ Each and every computer can share the data with another computer, connected through a ring topology.
- ➢ Can not send private message.
- ➢ It has low reliability.
- ➢ Token ring network are defined by IEEE 802.5 standard.
- ➢ Fiber Distributed Data Interface (FDDI) is a fast fiber optical network based on ring topology.



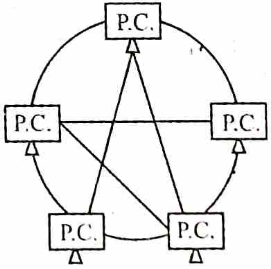
■ Star topology -

- ➢ All the node are connected with central device called HUB.
- ➢ Sharing the data is only possible through HUB.
- ➢ Easy to connect new P.C. without affecting rest of network.



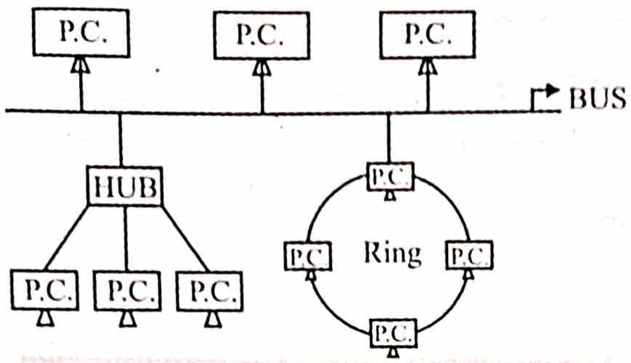
■ Mesh Topology -

- ➢ Each and every computer is directly connected with each other.
- ➢ Mesh topology is point to point link.
- ➢ It has highest reliability.



■ Hybrid topology -

- ➢ Combination of different topology -



❑ OSI (Open System Inter Connection) Model -

- ➢ OSI model is consist of 7 layer

1. Physical layer -

- ➢ To provide mechanical and electrical specification.
- ➢ To transmit bits over a medium.

2. Data link layer -

- ➢ To organized bits into frames.
- ➢ This layer is responsible for moving frame from one node to next node.
- ➢ This layer is also responsible for error controls, flow control and framing.

3. Network layer -

- ➢ This layer is responsible for source to destination delivery of packet.

☞ Remember -

bits → Physical layer
frame → Data link layer
packets → Network layer

4. Transport layer -

- ➢ The error at node can be detected by transport layer.
- ➢ The transport layer is also responsible to flow control and error control.

Note - The error between the nods can be detected by data link layer but the error at node can not be detected by data link layer.

- ➢ Transmission control layer (Transport layer) has two type -

(i) Transmission Control Protocol (TCP)
(ii) User Data-gram Protocol (UDP)

(i) TCP -

- ➢ Connection oriented and reliable transport protocol.
- ➢ It is used full duplex communication.
- ➢ Also called stream oriented protocol.

(ii) UDP -

- ➢ It is called connectionless and unreliable transport protocol.

5. Session layer -

- ➢ This layer is responsible to synchronies the interaction between communicating device.

6. Presentation layer -

- ➢ It is responsible for compression or de-compression.
- ➢ It is also responsible for encrypt and decrypt.

7. Application layer -

- ➢ This layer enable the user to access the network.

☞ Remember -

Session, presentation and application layer are the user support layer.

➢ IEEE	802.4	-	Token bus
IEEE	802.5	-	Token ring
IEEE	802.2	-	LLC layer
IEEE	802.3	-	Ethernet

❑ TCP/IP (Transmission Contro Protocol/Inter Networking Protocol)

- ➢ **TCP/IP protocol contains four layer -**

1. Host to network (Physical layer, Data link layer)
2. Internet (Network layer) layer
3. Transport layer
4. Application layer

Application layer	TELNET, SMTP, FTP, HTTP, DNS, SNMP
Transport layer	SCTP, TCP, UDP
Internet layer	ICMP, PCI, IP, RARP, ARP, IGMP, VL
Host to network layer	-------

☞ Remember -

- ➢ Four levels of address are used in an interne employing the TCP/IP protocols -

(i) Physical address -

- ➢ It is also known as link address.

(ii) Logical address -

(iii) Port address -

- ➢ It identify a process on a host.

(iv) Specific address -

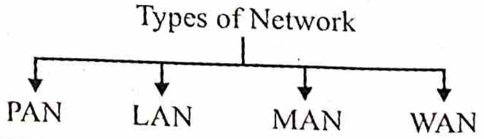
- ➢ It is user friendly address.

■ Difference between OSI and TCP/I model

OSI (Open system Interconnection)	TCP/IP (Transmission control protocol/Internet protocol)
It has 7 layers Application layer ← last layer Presentation layer Session layer Transport layer Network layer Data link layer Physical layer ← first layer	It has 4 layers Application layer ← last layer Transport layer Internet layer Host to Network layer ← first layer
Network layer guarantees the delivery of packets.	It does not guarantees delivery of packets.
Follow horizontal approach.	Follow vertical approach.
It provides connection oriented and Connectionless service.	It provides connectionless service.

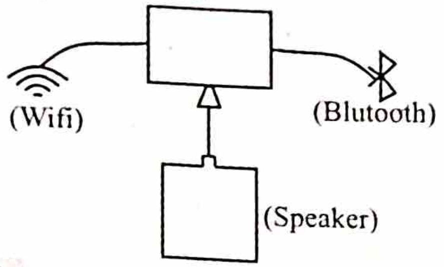
❑ Network type -

- ➢ It depends how large they are and how much are they cover.



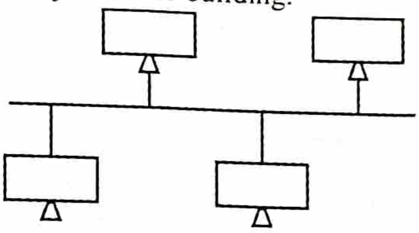
■ PAN -

- PAN stands for Personal Area Network.
- Range < 10 meter.
- Only for personal uses.


(Wifi)
(Blutooth)
(Speaker)

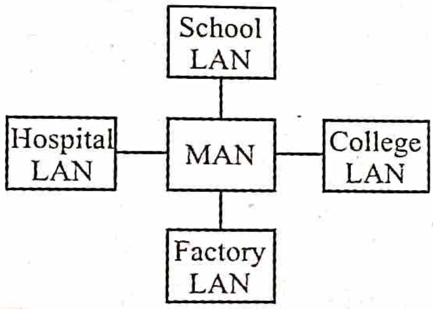
■ LAN -

- Stands for Local Area Network.
- Range < 150 meter.
- Uses in only office or building.



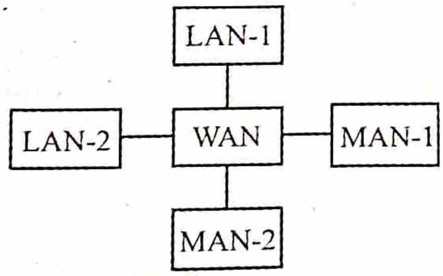
■ MAN -

- MAN stands for Metropolitan Area Network.
- Collection of LAN network is called MAN.
- Range < 50 Km.
- Used within city.


School LAN
Hospital LAN
MAN
College LAN
Factory LAN

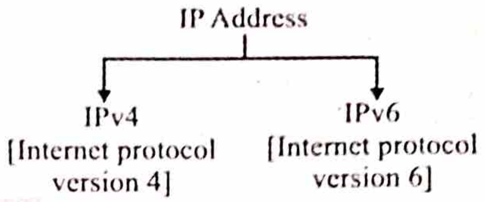
■ WAN -

- WAN stands for Wide Area Network.
- Collection of LAN and MAN Network.
- Range is not fixed.
- Uses between two country or all over the world.


LAN-1
LAN-2
WAN
MAN-1
MAN-2

❑ IP Address -

- IP stands for Internet Protocol.
- Unique number provided to each and every devices.


IP Address
IPv4
[Internet protocol version 4]
IPv6
[Internet protocol version 6]

■ IPv4 -

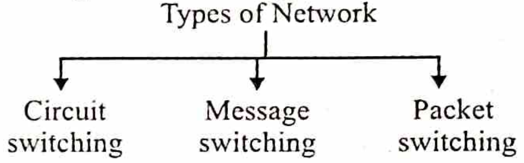
- Length = 32 bit
- Octet = 4
- Number uses = 0 to 255
- 2^{32} address location.

■ IPv6 -

- Length = 128 bits
- Octet = 8
- Number uses = 0 to 65535
- 2^{128} address location.

❑ Switching -

- Switching sends data along different routes.


Types of Network
Circuit switching
Message switching
Packet switching

■ Circuit switching -

- It is transmission mode that involves setting up a dedicated end to end communication.
- Commonly used in telephone systems.
- Connection oriented.
- No delay in data flow.
- More B.W. is required.

■ Message switching -

- There is no dedicated path between two communicating devices.
- Each message is treated as an independent unit and includes its own destination and source address.
- Efficient traffic management.
- Some delay due to storing and forwarding.

■ Packet switching -

- Messages are broken up into packets.
- Individual packets take different routes to reaches the destination.
- Required BW is less.

❑ High Level Data Link Control (HLDC) -

- Bit oriented data link protocol.
- It may be half or full duplex.

❑ Binary Synchronous Communication (BSC) -

- It is character oriented.
- It is used in both point to point and multipoint link.

- **Standard full form -**

IEEE →	Institute of Electrical and Electronics Engineering
FCC →	Federal Communication Commission
EIA →	Electronic Industries Association
ISO →	International Standard Organization

❑ Expansion Buses -

- ➢ The expansion bus allows the CPU to communicate with peripheral devices.

(i) ISA (Industry Standard Architecture) -

- ➢ Data lines = 16.
- ➢ Address lines = 24 bit.
- ➢ Low data transfer rate.

(ii) EISA (Extended Industry Standard Architecture)

- ➢ Data lines = 32 bit
- ➢ Address lines = 32 bit

(iii) PCI Bus (Peripheral Component Interconnect)

- ➢ Bus topology is used.
- ➢ PCI is a parallel bus.
- ➢ Key feature of the PCI bus is plug and play capacity.
- ➢ Data rate is 130 mbps and 33 MHz

(iv) AGP Bus (Accelerated Graphic Port)

- ➢ It is developed just for graphics.

(v) GPIB (General Purpose Interface Bus)

- ➢ Also known as IEEE - 488

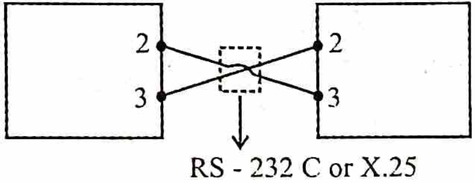
(vi) HPIB (Hewlett Packed Interface Bus)

- ➢ Used 24 wire cable.

(vii) VL BUS (VESA Local Bus)

❑ DCE and DTE -

DTE - Data Terminal Equipment
DCE - Data Communication Equipment



Pin 2 → T_xD [Transmitter Data]
Pin 3 → R_xD [Receiver Data]

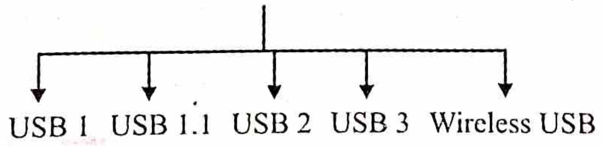
❑ RS - 232 C -

- ➢ Used for serial data communication.
- ➢ It is asynchronous data communication.
- ➢ It used negative logic.
- ➢ Support full duplex mode.
- ➢ It developed by EIA.
- ➢ Used for long distance communication.
- ➢ Also known as physical interface.
- ➢ Used in physical interface and electrical interface.

❑ USB (Universal Serial Bus) -

- ➢ It is replaced RS - 232 C.
- ➢ Serial data communication.
- ➢ It is a serial I/O interface between peripheral devices and computer.

Types of USB



- **USB 1 -**
- ➢ It supported wide range of devices.
- ➢ USB 1 allow transfer rate 12 Mbps.
- **USB 1.1 -**
- ➢ It support two modes
  (i) Full speed mode of 12 Mbps.
  (ii) Low speed mode of 1.5 Mbps.
- **USB 2 –**
- ➢ It is also known as hi-speed USB
- ➢ It support 3 mode -
  (i) Mod 1 → 1.5 Mbps
  (ii) Mod 2 → 12 Mbps
  (iii) Mod 3 → 480 Mbps
- **USB 3 -**
- ➢ Known as super speed USB
- ➢ Data transfer at the rate of 4.8 Gbps.
- **Wireless USB -**
- ➢ Data transfer at the rate of 480 Mbps.

❑ MODEM -

- ➢ Known as Modulator-Demodulator.
- ➢ Modulator convert binary data into analog signal.
- ➢ Demodulator recovered binary data from the modulated signal.
- **MODEM Standard -**

V - Series
V.32
V.34
V.90
V.92

❑ Network Connecting Device -

(i) Bridges
(ii) Router
(iii) Gateway
(iv) Switches
(v) HUB

❑ Digital Subscriber Line (DSL) -

- ➢ Used for provide higher speed access to the internet.
- ➢ DSL technology is a set of technology each deferring in the 1st letter.

A	DSL → Asymmetric DSL
H	DSL → High bit rate DSL
S	DSL → Symmetric DSL
V	DSL → Very high bit rate DSL

❑ Digital Signal Services -

Service	Line	rate(Mbps)	Voice channels
DS – 0	T – 0	64 kbps	1
DS – 1	T – 1	1.544 Mbps	24
DS – 2	T – 2	6.312 Mbps	96
DS – 3	T – 3	44.736 Mbps	672
DS – 4	T – 4	274.176 Mbps	4032

❑ X.25 is defined as three layer

(i) Physical layer
(ii) Data link layer
(iii) Packet layer

☞ Remember -

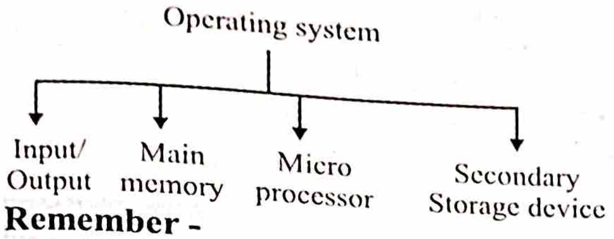
- ➢ X.25 network work as speed upto 64 kbps.
- ➢ X.25 signal is also used for DCE and DTE interfacing.
- ➢ X.25 support switched virtual circuit and permanent circuit.
- ➢ X.25 provide flow control, acknowledge signal.

❑ Fram relay -

- Uses virtual link only.
- Operate at higher speed of 1.5 Mbps.
- Does not provide flow controls acknowledgement.

❑ Operating system (OS) -

- The interaction between the hardware and software is manage by set of program is called operating system.



☞ Remember -

Booting (Boot Strapping) -

- Process of loading the operating system into memory (main memory) is known as booting.
- Boot strapping loader is always stored in ROM.

■ Types of operating system -

(i) MS-DOS (Microsoft Disk Operating System) -

- It is also called PC DOS (Personal Computer Disk Operating System)
- Single user operating system developed by micro soft.
- IBM version of MS-DOS is known as PC-DOS.
- Not provide graphics facility.

(ii) UNIX -

- Multitasking, multiuser operating system.
- It requires 8 to 10 MB of memory.

(iii) LINUX OS -

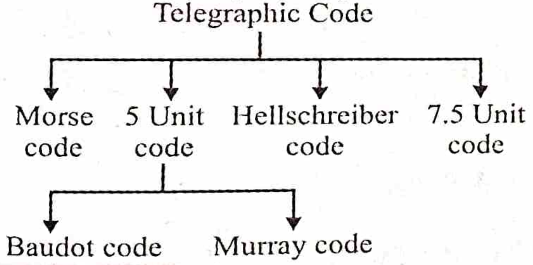
- Multitasking multiuser operating system.
- It is a version of UNIX.

(iv) Windows OS -

- It is a graphical user interface (GUI) of microsoft.
- GUI provided picture oriented interface.
- It is a single user, multitasking operating system. Example - Windows 3.0, Windows 3.1, Windows 3.11,

❑ Telegraphic codes -

- Information is send by the help of codes.



■ Morse Code -

- Information transmit in the form of dot and dash.

■ Murray Code -

- Also called CCITT code No. 2.
- CCITT (Consultative Committee for International Telegraph and Telephone.
- 5 Unit code.

■ 7.5 Unit code -

- Also called start stop code.

❑ Telegraphic speed :

■ Baud -

- Number of elements transmit per second.

■ WPM -

- Word per minute.
- Number of words transmit per minute.
- Speed in wpm =

$$\frac{1}{\text{No. of unit per word} \times \text{duration of smallest element (in minute)}}$$

$$= \frac{1}{N \times T(\text{in minute})}$$

❑ Some important full forms

SMTP	Simple Mail Transfer Protocol
SNMP	Simple Network Management Protocol
UDP	User Datagram Protocol
ICMP	Internet Control Message Protocol
ARP	Address Resolution Protocol
CRC	Cyclic Redundancy Check
PPP	Point to Point Protocol
HLDC	High Level Data Link Control
FTP	File Transfer Protocol
HTTP	Hyper Text Transfer Protocol
DNS	Domain Name System
MAC	Message Authentication Code
GSM	Global System for Mobile Communication
PCO	Public Call Office
Telex	Tele-printer Exchange
CDMA	Code Division Multiple Access
GPRS	General Packet Radio Service
ISDN	Integrated Service Digital Network
SIM	Subscriber Identify Module
TRAI	Telecom Regulatory Authority of India
VPN	Virtual Private Network
WPAN	Wireless Personal Area Network

❑ Satellite communication

■ Satellite

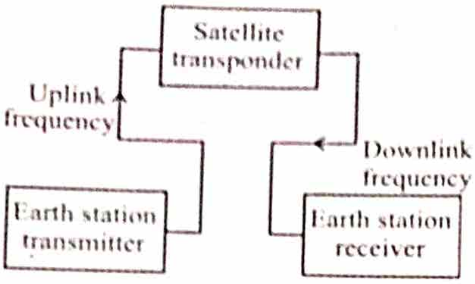
- Satellite is microwave repeater which is placed certain height above the ground.
- For satellite communication frequency should be greater than critical frequency of ionosphere.
- In satellite communication frequency division multiplexing is used.
- I^{st} satellite SPUTNIK 1 was launched in 1957 by Soviet Union.

● **UP link frequency -**

- The uplink frequency is transmitted frequency from earth to satellite.

● **Downlink frequency -**

- Downlink frequency is the transmitting frequency from satellite to earth.



Band Name	Band frequency (GHz)	Downlink frequency (GHz)	Uplink frequency (GHz)	Services
L	1-2	1.5	1.6	Mobile, Audio broadcasting, radio localization
S	2-4	1.9	2.2	Navigation
C	4-8	4	6	Satellite communication
X	8-12			Missile guidance
ku	12-18	11	14	Satellite transponders
k	18-26.5			Detecting clouds
ka	26.5-40	20	30	Airport surveillance

Classification of satellite -

- **Based on principle of operation -**

(i) Passive Satellite -

- It has no electronic components.
- Work as reflector.
- Not amplify the signal.
- Low communication capability.

(ii) Active Satellite -

- It has suitable electronic devices.
- Work as amplifier.
- High communication capability.
- **Example** - IRS - 1A, IRS - 1B

- **Based on altitude -**

(i) LEO (Low Earth Orbit) Satellite -

- Altitude (150 km to 1000 km)
- Velocity = 8 km/sec
- Path loss is less.
- Propagation delay time is less.
- Coverage area is less.

(ii) MEO satellite -

- Altitude 2000 km to 10000 km.
- GPS is generally MEO satellite.
- 24 satellite required to cover entire world.

(iii) GEO satellite -

- Situated on 36,000 km.
- Time period = 24 hour.
- Used 3 satellites to cover global earth.
- Coverage area is more.
- Path loss is more.

- **Difference between GEO-Stationary and GEO-Synchronous satellite**

GEO-Stationary	GEO-Synchronous
Circular orbit	Not circular orbit
In this satellite, the orbit appears to be stationary w.r.t. earth	In this satellite the orbit appears to oscillirate w.r.t. earth
There is one GEO-Stationary orbit	There can be many GEO-Synchronous orbit
Time period=23 hour 56 minute 4.1 sec.	Time period = 23 hour 56 minute 4.1 sec.

- **Based on orbit -**
  - (i) Equatorial orbit
  - (ii) Polar orbit
  - (iii) Inclined orbit

Polar orbit -

- Used for Earth mapping and Earth observation.
- Passes through north and south pole.
- Situated on (600-900) km height from the Earth.

☐ Kepler's Laws -

Kepler's first law	The law of orbits
Kepler's second law	The law of equal area
Kepler's third law	The law of periods $T^2 \propto r^3$

☐ Apogee and Perigee -

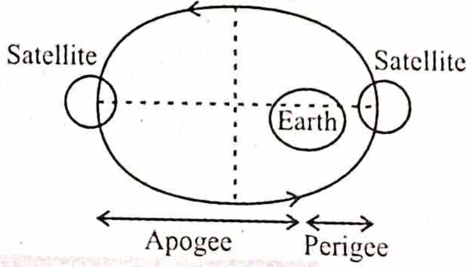
Apogee -

- Maximum distance between satellite and earth.
- Apogee distance = (a + ae).

  Where, e = eccentricity of ellipse
- Low velocity of satellite on Apogee point.

- **Perigee -**

- Minimum distance between satellite and earth.
- Perigee distance = (a – ae).
- High velocity of satellite on perigee point.



☐ Escape velocity [V_e] -

- $V_e = \sqrt{2gR}$

  Where,

  R = Radius of Earth
- Escape speed on Earth = 11.2 km/s

☐ Orbital velocity (V_o) -

- $V_o = \sqrt{gR}$

  Where,

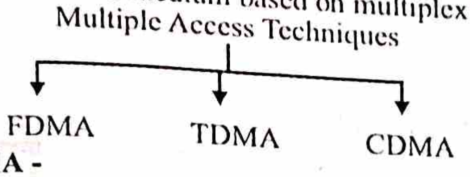
  R = Radius of Earth

☞ **Remember -**

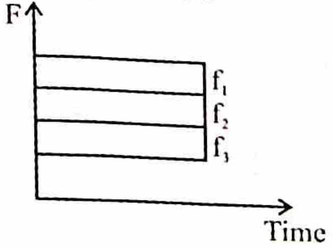
- Escape velocity is greater than $\sqrt{2}$ time of orbital velocity.

☐ Multiple Access Techniques -

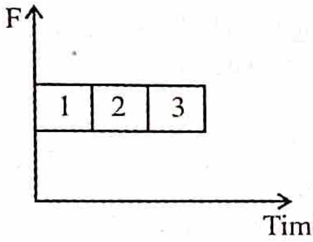
- ➢ Allow multiple terminals to share the common communication medium based on multiplexing.


Multiple Access Techniques
FDMA
TDMA
CDMA

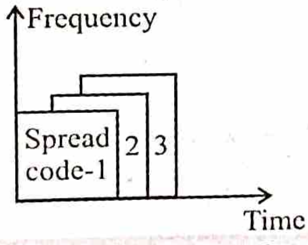
- • **FDMA -**
- ➢ FDMA stands for Frequency Division Multiple Access.
- ➢ Frequency band divided into small frequency channels.
- ➢ Different channels are allocated to different users.
- ➢ Multiple users can transmit at the same time but on different frequency channels.


F
f_1
f_2
f_3
Time

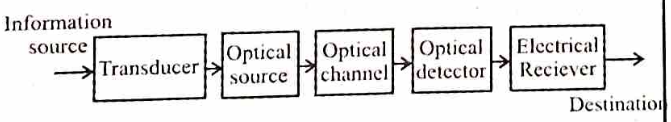
- • **TDMA -**
- ➢ TDMA stands for Time Division Multiple Access.
- ➢ Each user is allowed to transmit only in specified time-slots. With common frequency bands.
- ➢ Multiple users can transmit at the same frequency band at different times.



- • **CDMA -**
- ➢ CDMA stands for Code Division Multiple Access.
- ➢ User may transmit at the same time using the same frequency band but using different codes.


Frequency
Spread code-1
2
3
Time

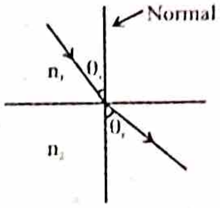
☐ Optical fiber communication


Information source
Transducer
Optical source
Optical channel
Optical detector
Electrical Reciever
Destination

■ Snell's law -

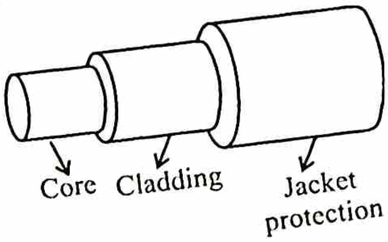
$n_1 \sin\theta_i = n_2 \sin\theta_r$

- ➢ n_1 and n_2 is refractive index of the different mediums.

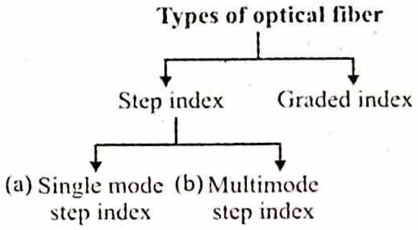

Normal
n_1
θ_i
θ_r
n_2

■ Optical fiber -

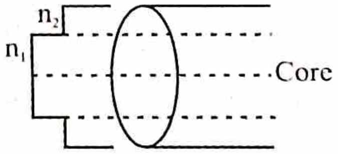
- ➢ An optical fiber consists of three basic elements.
  (i) Core **(ii)** Cladding **(iii)** Outer jacket
- ➢ Works on the principle of total internal reflection (T.I.R.).


Core
Cladding
Jacket protection

- ➢ Refractive index of core (1.5) is always greater than refractive index of cladding (1.48).
- ➢ Transmission rate 25 GHz/sec.
- ➢ Made from glass or silica (SiO_2).


Types of optical fiber
Step index
Graded index
(a) Single mode step index
(b) Multimode step index

- • **Step index fiber -**
- ➢ Refractive index of core is uniform.
- ➢ Refractive index abruptly changes from core to cladding.



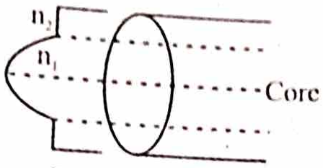
Profile of step index fiber

(a) Single mode step index -

- ➢ Center core diameter = 5 μm to 10 μm.
- ➢ Well defined boundary between core and cladding.
- ➢ Light propagates in straight line.
- ➢ High accuracy.

(b) Multi mode step index -

- ➢ Center core diameter = 50 μm.
- ➢ Well defined boundary between core and cladding.
- ➢ More than one mode can propagates.
- ➢ Low cost.
- • **Graded index fiber -**
- ➢ Variable refractive index inside the core.
- ➢ Refractive index is maximum at center of core and decreases as radial distance increases from the core.



Profile of Graded index fiber

❑ Numerical aperture -

- ➢ Measure of light collecting ability of fiber.
- ➢ $\text{N.A.} = \sqrt{(n_1)^2 - (n_2)^2}$
- ➢ $\text{N.A.} = n_1\sqrt{1 - \text{Sin}^2\phi_c}$

❑ Acceptance angle -

- ➢ Maximum value of incident angle to propagate a light signal into fiber.

  $\theta_a = \text{Sin}^{-1}[\text{NA}]$

❑ Meridional ray -

- ➢ It passes through core axis.
- ➢ Essay to track the path of meridional rays.
- ➢ It classified in two type.

  (a) Bound ray (b) Unbound ray

❑ Skew Ray -

- ➢ Not passes through core axis.
- ➢ Difficult to track.
- ➢ Follow helical path.

☞ Remember Point -

Acceptance angle of skew rays is always greater than acceptance angle of meridional rays.

❑ Splices -

- ➢ It is permanent joint.
- ➢ Used in optical fiber.
- ➢ Two type of splices.

  (i) Mechanical splices **(ii)** Fusion splices

❑ Connector -

- ➢ It is temporary joint.
- ➢ Essay to coupling and decoupling of fiber.

❑ Fiber coupler -

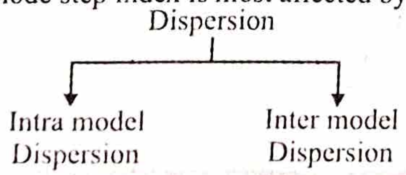
- ➢ Used to distribute the light from main fiber to branch fiber.

❑ Isolators -

- ➢ Unidirectional.
- ➢ Allow the transmission of light in only one direction.
- ➢ Used to prevent the back reflection of light in fiber.

❑ Dispersion -

- ➢ Dispersion ↑↑ pulse broadening ↑↑ B.W. ↓↓ Information carrying capacity ↓↓ system will be slow.
- ➢ Multimode step index is most affected by dispersion.



❑ RIP [Refractive Index Profile] -

- ➢ It controls the B.W.
- ➢ Measured by transferred near field method.

❑ Attenuation -

- ➢ $\text{Attenuation (In dB)} = 10\log\left(\frac{P_i}{P_0}\right)$.
- ➢ Caused by absorption, scattering and bending losses.

❑ Bending losses -

- ➢ Bending losses are two types.
- **Macro bending loss -**
- ➢ Due to curvature of the bend is much larger than fiber diameter.
- **Micro bending loss -**
- ➢ Due to discontinuity of fiber.
- ➢ It increases by external forces.

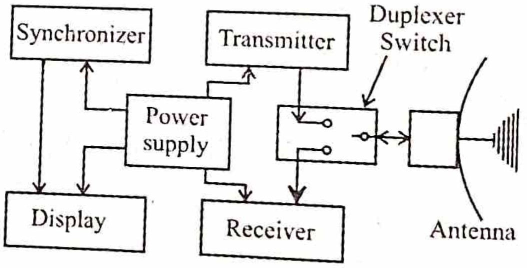
❑ Linear scattering losses -

- ➢ It is two type
- **Rayleigh scattering losses -**
- ➢ $\gamma_R = \frac{8\pi^3}{3\lambda^4} n^8 \rho^2 \beta_C K T_F$
- ➢ Occurs when the size of the density fluctuation is less than one-tenth of the operating wavelength of light.
- ➢ Rayleigh scattering loss $\alpha \frac{1}{\lambda^4}$.
- **Mie scattering losses -**
- ➢ Occurs when the size of the defect is greater than one-tenth of the wave length of light.

❑ RADAR

■ Radar [Radio Detection and Ranging] -

- ➢ Electro-magnetic device.
- ➢ Detect the presence and location of any object or target.



Radar block diagram

■ Duplexer -

- ➢ Switch that alternately connects the transmitter or receiver to the antenna.
- ➢ Purpose to protect the receiver from the high power output of the transmitter.
- ➢ Duplexer permits same antenna to be used for transmission and reception.
- ➢ Duplexer is used to isolate the transmitter and receiver during transmission and reception.

■ Power density (PD) -

- ➢ $\text{PD} = \frac{P_T}{4\pi r^2}$ [If antenna is isotropic]
- ➢ $\text{PD} = \frac{P_T . A_{er}}{4\pi r^2}$ [If antenna is directional]

■ Duty - Cycle -

- ➢ Duty cycle is the fraction of one period in which a signal or system is active.
- ➢ Duty cycle = $\frac{T_{ON}}{T_{ON}+T_{off}}$

■ Radar resolution (Range resolution)-

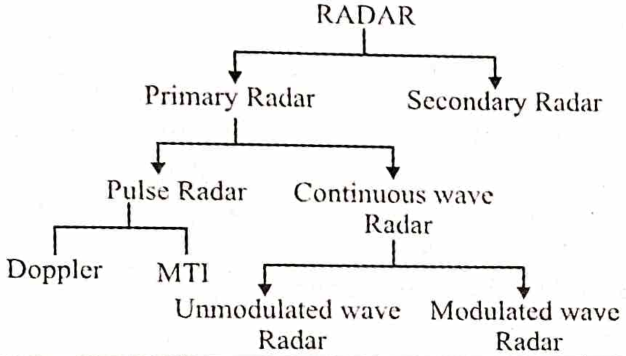
- ➢ Minimum distance over which radar can detect two target at a given time.
- ➢ For higher range resolution pulse width should be minimum.

$$\text{Radar resolution} \propto \text{B.W.} \propto \frac{1}{\text{Pulse width}}$$

■ Maximum range of RADAR -

$$R_{max} = \left[\frac{P_t\sigma\left(\frac{4\pi A_{er}}{\lambda^2}\right)^2\lambda^2}{(4\pi)^3 S}\right]^{1/4}$$

Where, A_{er} = Radar aperture cross sectional area
S = Received power at radar antenna



Primary Radar	➢ Received its own echoes.
Secondary Radar	➢ Transmits high frequency transmission pulses.
Pulse Radar	➢ Transmit power pulses ➢ Pulse RADAR provides range and position of the target. ➢ It will not provide velocity of target, this is the main disadvantage of pulse RADAR. ➢ Doppler effect can not be used for pulse RADAR.
Continuous Wave Radar	➢ Transmit high power continuous signal. ➢ CW RADAR provide velocity of target. ➢ CW RADAR is not find the range of target.
Un-modulated Wave Radar	➢ Transmitted signal is of constant amplitude and frequency.
Modulated Wave Radar	➢ Transmitted signal is frequency modulated.

■ Blind Speed -

- ➢ $V_{blind} = \frac{\lambda}{2T}$

Where,
T = Pulse repetition time (PRT)

■ RADAR Beacons -

- ➢ It is used for target identification.
- ➢ It is used for Navigation.
- ➢ It is used in aircraft for traffic control.

☞ **Remember -**

- ➢ **IFF** - Identification of friend or foe.
- ➢ **OME** - Distance measuring equipment.
- ➢ **VOR** - VHF Omni directional Range.

❑ Need of Doppler effect in radar technology-

- ➢ Speed measuring.
- ➢ Moving target indication.

❑ Doppler Frequency -

- ➢ $f_d = \frac{2v_r}{\lambda}$

Where, v_r = relative velocity of target with respect to radar

- ➢ $R_{max} = \frac{c}{2f_d}$

Where,
c = Velocity of light in free space
R_{max} = target of run-ambiguous

❑ Mobile Communication

■ Radio Pager -

- ➢ One way mobile communication.
- ➢ Wireless Tele communication device.
- ➢ Small personal radio receiver.
- ➢ Also known as beeper or bleeper.

■ Hand off -

- ➢ Process of transferring an active call on data from one cellular network to another cellular network.
- ➢ It takes approximate 300 m/sec.

■ GSM -

- ➢ GSM stands for Global System for Mobile Communication.
- ➢ It is a digital mobile telephony system.
- ➢ Its uses TDMA technique.
- ➢ it operates on 900 MHz or 1800 MHz frequency.
- ➢ Gaussian minimum shifting keying (GMSK) modulation used in GSM.

■ GPRS -

- ➢ GPRS stands for General Packet Radio Services.
- ➢ It is packet based wireless communication.
- ➢ It is communication service based or GSM.
- ➢ High data rate.

■ GPS -

- ➢ GPS stands for Global Positioning System.
- ➢ GPS used in navigation field, automobile guidance, hacking and aircraft landing.
- ➢ It is space-based satellite navigation system.
- ➢ GPS consist three parts.
  (i) Space segment
  (ii) Control segment
  (iii) Uses segment

Microwave Engineering

- ➢ The term of microwave is used to describe electromagnetic waves with frequencies 300MHz to 300 GHz. The corresponding wavelength $\left(\lambda = \frac{c}{f}\right)$ range is 1m up to 1mm for 300 MHz to 300 GHz waves.
- ➢ Microwave frequency range is (10^9Hz to 10^{13}Hz).
- ➢ Microwave is used for terrestrial range and can't be used for ground wave communication.
- ➢ For microwave frequency $\frac{\sigma}{\omega \in} << 1$, ground behaves as dielectric so can't reflect back the EM waves at microwaves frequencies.

- **Properties of microwaves**

- ➢ Radiates electromagnetic energy with shorter wavelength.
- ➢ Not reflected by ionosphere.
- ➢ Travel in a straight line and reflected by the conducting surfaces.
- ➢ Easily attenuate within shorter distance.
- ➢ Microwave currents can flow through a thin layer of a cable.

- **Advantages of microwaves**

- ➢ Supports larger bandwidth (Higher data rates)
- ➢ More antenna gain is possible.
- ➢ Antenna size gets reduced (as higher frequencies)
- ➢ Effect of fading gets reduced (by LOS propagation)
- ➢ Provides effective reflection area in the radar systems.
- ➢ Satellite and terrestrial communications with high capacities are possible.
- ➢ Low-cost miniature microwave components can be developed.

- **Disadvantages of microwave**

- ➢ Installation cost is high.
- ➢ Occupy more space.
- ➢ Electromagnetic interference may occur.
- ➢ Inherent in efficiency of electric power.
- ➢ Variations in dielectric properties.

- **Applications of microwave**

- ➢ Wireless communication
- ➢ Navigation
- ➢ Research application
- ➢ Food industry
- ➢ Medical application
- ➢ Commercial uses
- ➢ Military and Radar
- ➢ Radio astronomy
- ➢ Industrial uses

■ EM wave spectrum

Frequency (f) range	Wavelength (λ) range	EM Spectrum Nomenclature	Typical Application
30 - 300 Hz	$10^7 - 10^6$ m	Extremely low frequency (ELF)	Power line communication
0.3 - 3 kHz	$10^6 - 10^5$ m	Voice frequency (VF)	Face to face speech, communication intercom
3 - 30 kHz	$10^5 - 10^4$ m	Very low frequency (VLF)	Submarine communication
30 - 300 kHz	$10^4 - 10^3$ m	Low frequency (LF)	Marine communication
0.3 - 3 MHz	$10^3 - 10^2$ m	Medium frequency (MF)	AM broadcasting
3 - 30 MHz	$10^2 - 10^1$ m	High frequency (HF)	Landline telephony
30 - 300 MHz	$10^1 - 10^0$ m	Very high frequency (VHF)	FM broadcasting, TV
0.3 - 3 GHz	$10^0 - 10^{-1}$ m	Ultra high frequency (UHF)	TV, cellular telephony
3 - 30 GHz	$10^{-1} - 10^{-2}$ m	Super high frequency (SHF)	Microwave oven, radar
30 - 300 GHz	$10^{-2} - 10^{-3}$ m	Extremely high frequency (EHF)	Satellite communication, radar
0.3 - 3 THz	0.1 – 1 mm	Experimental	For all new explorations
3 - 430 THz	100 – 0.7 μm	Infrared	LED, Laser, TV remote
430 - 750 THz	0.7 – 0.4 μm	Visible light	Optical communication
750 - 3000 THz	0.4 – 0.1 μm	Ultraviolet	Medical application
> 3000 THz	< 0.1 μm	X-rays, gamma rays, cosmic rays	Medical application

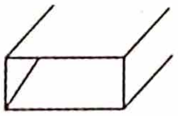
- **IEEE bands for Microwave-**

Designation	Frequency range
L	1-2 GHz
S	2-4 GHz
C	4-8 GHz
X	8-12 GHz
Ku	12-18 GHz
K	18-27 GHz
Ka	27-40 GHz

- **Comparison between waveguide and Transmission line**

Waveguide	Transmission line
Metal waveguides are typically one conductor filled with an insulating medium (Rectangular, circular, cylindrical)	Two or more conductors separated by some insulating medium (Two wire, micro strip, coaxial etc)
Lower signal attenuation at high frequencies than transmission line.	Significant signal attenuation at high frequencies due to conductor and dielectric losses.
Large cross section (low frequency) waveguides are impractical due to large size and high cost.	Large cross section transmission line (like power transmission lines) can transmit high power level.

➢ Maxwell's equation predicts that electromagnetic waves can also be guided through metallic tubes. Two common metallic waveguides, rectangular and circular cross section.



Rectangular waveguide

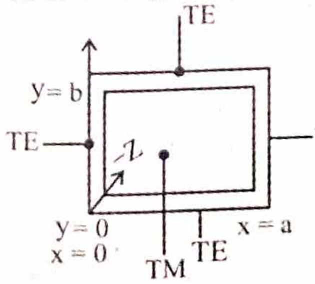
Circular waveguide

- **Waveguide :** A waveguide is a structure that guides wave, such as electromagnetic wave or sound, with minimum loss of energy by restricting the transmission of energy to one direction without the physical constraint of waveguide.

➢ Waveguide, like transmitter are used to guide electromagnetic wave from one point (Source) to another (load).

➢ A waveguide section in a microwave circuit acts as a high pass filter.

Rectangular waveguide-



- **Helmholtz equation -** The electric and magnetic wave equations in frequency domain.-

$$\boxed{\begin{aligned}\nabla^2 E &= \gamma^2 E\\ \nabla^2 E &= \gamma^2 H\end{aligned}}$$

Where

γ = propagation constant of EM wave

E, H= Electric and Magnetic field.

- **Boundary condition-** If the cross section of the wave guide is the rectangle, the boundary condition are such that the tangential electric field is zero on all the PEC walls. $\boxed{\begin{aligned}E_{\text{tang}} &= 0\\ H_{\text{Norm}} &= 0\end{aligned}}$

E_{tang}- Tangential component of electric field at conductor surface.

H_{norm} - Normal component of magnetic field at conductor surface.

- **Propagation constant:**

$$\boxed{\bar{\gamma} = \sqrt{\left(\frac{m\pi}{a}\right)^2 + \left(\frac{n\pi}{b}\right)^2 - \omega^2\mu_0\varepsilon_0}}$$

Where,

$\bar{\gamma}$ = Propagation constant along z-axis

$\left(\frac{m\pi}{a}\right)^2$ = Propagation constant along x-axis

$\left(\frac{n\pi}{b}\right)^2$ = Propagation constant along y-axis

m, n is integer value.

➢ If $\bar{\gamma}$ is real quantity, then wave will not propagate through waveguide rather it attenuates.

➢ If $\bar{\gamma}$ is imaginary quantity, then wave will propagate through waveguide.

- **Cut-off frequency (f_c) :**

$$\boxed{f_c = \frac{c}{2\pi}\sqrt{\left(\frac{m\pi}{a}\right)^2 + \left(\frac{n\pi}{b}\right)^2}}$$

H_z → For free space.

a, b → waveguide dimensions

m, n → number of half cycle completed by the wave between the guide walls or number of maxima between guide wall or number of P-phase completions.

➢ Cut-off frequency for waveguide where medium is perfect dielectric-

$$\boxed{f_c = \frac{c}{2\pi\sqrt{\mu_r\,\epsilon_r}}\sqrt{\left(\frac{m\pi}{a}\right)^2 + \left(\frac{n\pi}{b}\right)^2}}$$

➢ If frequency for a particular mode is greater than cut off frequency then wave will travel through waveguide.

- ➢ If frequency is equal to cut off frequency, then wave will oscillate between the walls of waveguide.
- ➢ If frequency is less than cut-off frequency then wave will not propagate through waveguide.

- **Cut-off wave number (K_C) :**

$$\boxed{K_C = \sqrt{\left(\frac{m\pi}{a}\right)^2 + \left(\frac{n\pi}{b}\right)^2}}$$

- **Phase velocity(V_p):** Phase velocity is defined as the rate at which the wave changes its phase in terms of the guide wavelength $\boxed{V_p = \dfrac{c}{\sqrt{1-\left(\dfrac{f_c}{f}\right)^2}\sqrt{\mu_r \in_r}}}$

When, $\boxed{V_p > c}$

For waveguide medium assumed to be free space.

$$\boxed{V_p = \frac{c}{\cos\theta}}$$

- **Group velocity (V_g):** Group velocity is defined as the rate at which wave propagates through waveguides.

$$V_g = \frac{c}{\sqrt{\mu_r \in_r}}\sqrt{1-\left(\frac{f_C}{f}\right)^2}$$

$\boxed{V_g = c\cos\theta}$ for waveguide medium assumed to be free space.

- ➢ Group velocity signifies the physical rate of energy transfer along the guide axis.

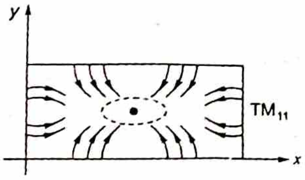
Note :- $\boxed{V_p > c > V_g}$

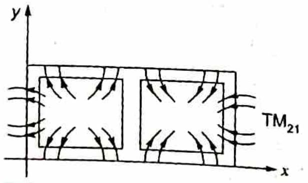
where V_p = Phase velocity
c = Velocity of light
V_g = Group of velocity

- **Wave/Tilt angle:** $\boxed{\cos\theta = \sqrt{1-\left(\dfrac{f_c}{f}\right)^2}}$

Where θ is wave angle or tilt angle.

- ■ **TM Mode-** Transverse magnetic modes, A mode refers to a feed mechanism involving the number of connections or feed points and the position of feed points. This is called TM mode because magnetic field is perpendicular to the direction of wave propagation, that is for TM mode H_X and H_Y exist but H_Z will be zero.





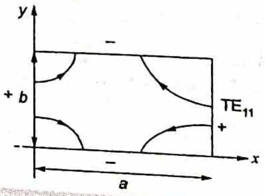
$$\boxed{H_z = 0}$$

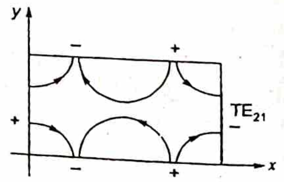
- ➢ If any of the m and n is zero, then E_z will be zero and wave will not exist so m and n can not be zero for TM mode.
- ➢ The mode which does not exist inside a waveguide are called evanescent modes.
- ➢ TM_{on} and TM_{mo} are evanescent modes for rectangular wave guide.

■ **Parameters:**

Phase constant	$\beta_g = \omega\sqrt{\mu\in}\sqrt{1-\left(\frac{f_c}{f}\right)^2}$
Waveguide wavelength (λg)	$\lambda_g = \dfrac{\lambda}{\sqrt{1-\left(\frac{f_c}{f}\right)^2}}$ Where, $\lambda = \dfrac{1}{\sqrt{\mu\in}f} = \dfrac{c}{\sqrt{\mu_r \in_r}}\cdot\dfrac{1}{f}$ Where μ_r and $\in_r$ are relative permittivity and relative dielectric constants of medium of waveguide.
Wave impedance (Z_g)	$Z_g = \sqrt{\dfrac{\mu}{\in}}\sqrt{1-\left(\frac{f_c}{f}\right)^2}$
Group velocity (V_g)	$V_g = \dfrac{c}{\sqrt{\mu_r \in_r}}\times\sqrt{1-\left(\frac{f_c}{f}\right)^2}$
Power Transmitted (P_{tr})	For TM_{mn} modes, the average power transmitted through a rectangular waveguide. $P_{tr} = \dfrac{1}{2\sqrt{\frac{\mu}{\varepsilon}}\sqrt{1-\left(\frac{f_c}{f}\right)^2}}\int_0^b\int_0^a\left(\lvert E_X\rvert^2 + \lvert E_y\rvert^2\right)dxdy$

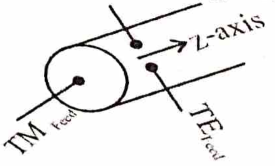
■ **TE Mode:** TE mode is also known as H mode. There is only a magnetic field along the direction of propagation





Note-
TE_{10} mode is dominant mode inside a rectangular waveguide if a > b
TE_{01} mode is dominant mode inside a rectangular guide if b > a

■ **Cylindrical (or circular) waveguide :**



A cylindrical waveguide which is simply a hollow tube with circular cross section of radius and extending along the Z-direction.

- **Helmholtz equation**

$$\boxed{\begin{aligned}\nabla^2 E &= \gamma^2 E\\ \nabla^2 H &= \gamma^2 H\end{aligned}}$$

γ = propagation constant of EM wave.

E, H = Electric and Magnetic field.

- **Boundary condition :**

  In case of cylindrical waveguide there is only one boundary condition that is at

  $\rho = a$

  $E_{tang} = 0$, $H_{norm} = 0$

- **Propagation constant :**

$\bar{\gamma}$ is propagation constant along guide axis and β_ρ is phase constant in ρ direction then $\bar{\gamma}$ is given by

$$\boxed{\bar{\gamma} = \sqrt{\beta_\rho^2 - \omega^2 \mu \in}}$$

Where $\beta_\rho = \omega\sqrt{\mu \in}$ is phase constant in the medium inside waveguide when there is no waveguide.

➢ Since at boundary, curvature of cylinder is involved so solution does not involve linear trigonometry function like (sin θ, cos θ) but solution will be of the type sin (sin θ), cos(cos θ) that is Bessel function.

➢ Solution along the guide walls is of the type in $J_n(\beta_\rho . \rho)$ where n is order of Bessel function.

➢ There are two sets of mode, TE and TM modes, which can propagate in cylindrical waveguide.

Parameter	TE Mode	TM Mode
Propagation constant $(\bar{\gamma})$	$\bar{\gamma} = \sqrt{\left(\frac{X'_{np}}{a}\right) - \omega^2 \mu \in}$	$\bar{\gamma} = \sqrt{\left(\frac{X_{np}}{a}\right)^2 - \omega^2 \mu \in}$
Cut of Frequency (f_C)	$f_C = \frac{c}{2\pi\sqrt{\mu_r \in_r}} \times \frac{X'_{np}}{a}$	$f_C = \frac{X_{np}}{2\pi a\sqrt{\mu \in}}$
Phase velocity (V_P)	$V_P = \frac{1}{\sqrt{\mu \in}\sqrt{1-\left(\frac{f_c}{f}\right)^2}}$	$V_P = \frac{1}{\sqrt{\mu \in}\sqrt{1-\left(\frac{f_c}{f}\right)^2}}$
Guide wavelength (λ_g)	$\lambda_g = \frac{\lambda}{\sqrt{1-\left(\frac{f_c}{f}\right)^2}}$ where, $\lambda = \frac{1}{\sqrt{\mu \in}} . \frac{1}{f}$	$\lambda_g = \frac{\lambda}{\sqrt{1-\left(\frac{f_c}{f}\right)^2}}$ where, $\lambda = \frac{1}{f\sqrt{\mu \in}}$
Characteristic impedance Z_g	$Z_g = \frac{\sqrt{\frac{\mu}{\in}}}{\sqrt{1-\left(\frac{f_c}{f}\right)^2}}$	$Z_g = \sqrt{\frac{\mu}{\in}}\sqrt{1-\left(\frac{f_c}{f}\right)^2}$
Power transmitted (P_{tr})	$P_{tr} = \frac{1}{2\sqrt{\frac{\mu}{\in}}\sqrt{1-\left(\frac{f_c}{f}\right)^2}}$ $\int_0^{2\pi}\int_0^a \left(\lvert E_\rho\rvert^2 + \lvert E_\phi\rvert^2\right)\rho d\rho d\phi$	$P_{tr} = \frac{\sqrt{1-\left(\frac{f_c}{f}\right)^2}.}{2\sqrt{\frac{\mu}{\in}}}\int_0^{2\pi}\int_0^a \left(\lvert E_\rho\rvert^2\lvert + E_\phi\rvert^2\right)\rho d\rho d\phi$

➢ TEM mode does not exist inside cylindrical waveguide. TEM mode can be supported in two conductors system only.

➢ Cut off frequency in case cylindrical waveguide for TE and TM mode is different while it is same in case of rectangular waveguide.

➢ TE_{11} mode is dominant mode inside cylindrical waveguide not TM_{01}.

➢ TM_{no} mode does not exist inside waveguide called evanescent mode but TM_{op} for p = 1, 2, 3 exist inside cylindrical waveguide.

➢ TE_{op} and TE_{1p} are degenerated mode in cylindrical waveguide.

➢ Single mode operation is used only in dominant mode.

■ **Cavity Resonator:** Cavity resonator are important component of microwave and optical system.

- An electronic device consisting of a space usually enclosed by metallic wall.
- Cavity resonator is a closed confined conducting structure operating at $\overline{\gamma} = 0$ conditions.
- Cavity resonator is used to produce microwave frequencies or microwave signal by giving energy or power periodically.

■ **Rectangular cavity resonator :**

- TE mode H_z is given by

$$H_z = H_{z0}\cos\left(\frac{m\pi x}{a}\right)\cos\left(\frac{n\pi y}{b}\right)\sin\left(\frac{p\pi z}{d}\right)$$

Where a, b, d are dimension of cavity.

- For TM mode E_z is given by

$$E_z = E_{z0}\sin\left(\frac{m\pi x}{a}\right)\sin\left(\frac{n\pi y}{b}\right)\cos\left(\frac{p\pi z}{d}\right)$$

- For lossless dielectric and for both TE and TM mode, resonant frequency

$$f_r = \frac{1}{2\sqrt{\mu \in}}\sqrt{\left(\frac{m}{a}\right)^2 + \left(\frac{n}{b}\right)^2 + \left(\frac{p}{d}\right)^2}$$

- A rectangular cavity is a rectangular waveguide closed at both the ends.

■ **Circular Cavity Resonator-** An electronic device consist of a space usually enclosed by metallic walls. A circular cavity resonator is a circular waveguide with two ends closed.

- For TE mode H_z is

$$H_z = H_{z0}J_n\left(\frac{X'_{np}\rho}{a}\right)\cos(n\phi)\sin\frac{(q\pi z)}{d}$$

- For TE mode Resonant Frequency

$$f_r = \frac{1}{2\pi\sqrt{\pi \in}}\sqrt{\left(\frac{X'_{np}}{a}\right)^2 + \left(\frac{q\pi}{d}\right)^2}$$

- For TM mode E_z =

$$E_z = E_{z0}J_n\left(\frac{X_{np}\rho}{a}\right)\cos(n\phi)\cos\left(\frac{q\pi z}{d}\right)$$

- For TM mode resonant frequency

$$f_r = \frac{1}{2\pi\sqrt{\mu \in}}\sqrt{\left(\frac{X_{np}}{a}\right)^2 + \left(\frac{q\pi}{d}\right)^2}$$

■ **Q-factor:** Quality factor is measure of frequency selectivity of a resonant or anti-resonant circuit.

$$Q = 2\pi\frac{\text{Maximum Energy Stored}}{\text{Energy dissipated per cycle}}$$

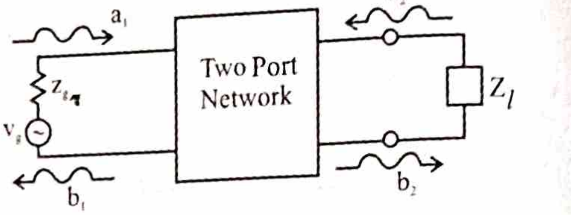
- The resonant frequency and unloaded Q_0 of a cavity resonator

$$f_0 = \frac{1}{2\pi\sqrt{LC}}, \quad Q_0 = \frac{\omega_0 L}{R}$$

■ **Microwave Hybrid circuit :** Microwave circuit consists of several microwave devices connected in some way to achieve the desired transmission of a microwave signal.

The interconnection of two or more microwave devices may be regarded as a microwave Junction.

- **S-Parameter:** S-parameter (also called s-matrix or scattering parameters) represents the linear characteristic of RF electronic circuit and component S-parameter of two port network-

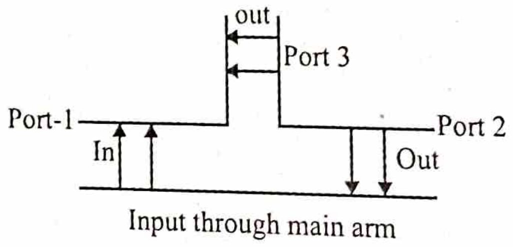


$$\boxed{\begin{aligned} b_1 &= S_{11}a_1 + S_{12}a_2 \\ b_2 &= S_{21}a_1 + S_{22}a_2 \end{aligned}}$$

- [S] Matrix is always a square matrix of order (nxn) where 'n' = numbers of ports.
- Matrix is a symmetric matrix.

■ **Tee Junction :-** Microwave waveguide Tee Junction is used for the purpose of connecting a branch or a section of waveguide is a series or parallel to the main waveguide.

- **There are three types :**
- **E-plane tee:** E-plane tee is a waveguide tee in which axis of side arm is parallel to the E field of a main waveguide.



- for E plane tee = $S_{13} = -S_{23}$
- S-matrix of E-plane tee

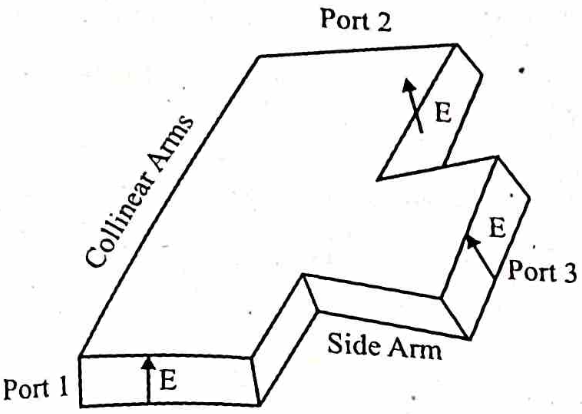
$$S = \begin{bmatrix} S_{11} & S_{12} & S_{13} \\ S_{12} & S_{11} & -S_{13} \\ S_{13} & -S_{13} & S_{33} \end{bmatrix}$$

- for the symmetry property of S-matrix.

$$\boxed{S_{12} = S_{21},\ S_{13} = S_{31},\ S_{23} = S_{32}}$$

- E-plane tee is also called series tee.

- **H-Plane Tee:** A H-plane tee is a waveguide tee in which the axis of the side arm is shunting E-field parallel to H-field of the main waveguide.

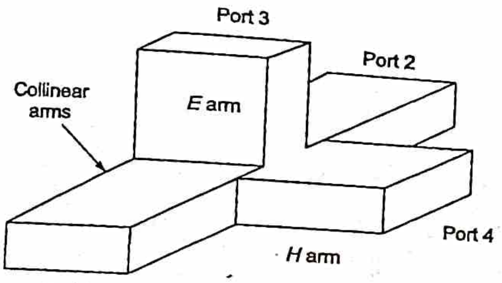

Port 2
E
E
Port 3
Collinear Arms
Side Arm
Port 1
E

- For H-plane tee $\boxed{S_{13} = S_{23}}$
- S-matrix for H-plane tee

$$S = \begin{bmatrix} S_{11} & S_{12} & S_{13} \\ S_{12} & S_{11} & S_{13} \\ S_{13} & S_{13} & S_{33} \end{bmatrix}$$

- H-Plane Tee is also called shunt tee.

- **Hybrid Tee or magic Tee:** It is combination of H plane Tee and E-plane Tee


Port 3
Port 2
Collinear arms
E arm
Port 4
H arm
Port 1

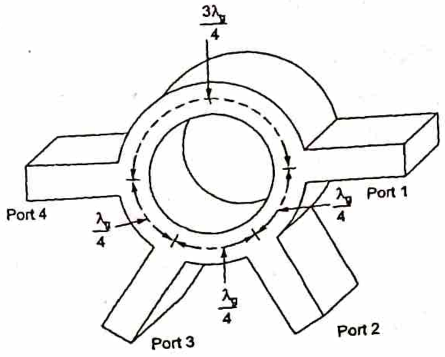
Magic Tee

S matrix of Hybrid tee

$$S = \begin{bmatrix} 0 & 0 & S_{13} & S_{14} \\ 0 & 0 & S_{23} & S_{24} \\ S_{31} & S_{32} & 0 & 0 \\ S_{14} & S_{24} & 0 & 0 \end{bmatrix}$$

- Magic tee is used in duplexer, mixer and measure unknown impedance.

■ **Hybrid ring or Rate-race circuit:** A rate -race also known as hybrid ring.


$\frac{3\lambda_g}{4}$
Port 4
$\frac{\lambda_g}{4}$
$\frac{\lambda_g}{4}$
Port 1
$\frac{\lambda_g}{4}$
Port 3
Port 2

Hybrid Ring

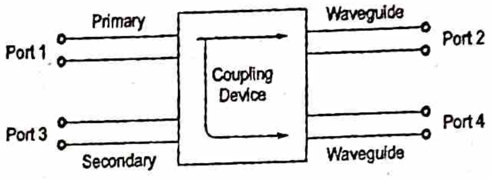
- S-Matrix of hybrid ring

$$S = \begin{bmatrix} 0 & S_{12} & 0 & S_{14} \\ S_{12} & 0 & S_{23} & 0 \\ 0 & S_{23} & 0 & S_{34} \\ S_{14} & 0 & S_{34} & 0 \end{bmatrix}$$

- The total circumference is 1.5 λ_g, where λ_g is guided wavelength.
- In Radar system the term rat-race is used in connection with duplexer.

■ **Directional couplers :** Directional couplers are passive devices used mostly in the field of radio technology.

- It has four port waveguide function.


Primary
Waveguide
Port 1
Port 2
Coupling Device
Port 3
Port 4
Secondary
Waveguide

S matrix of a directional coupler

$$S = \begin{bmatrix} 0 & P & 0 & jq \\ P & 0 & jq & 0 \\ 0 & jq & 0 & P \\ jq & 0 & P & 0 \end{bmatrix}$$

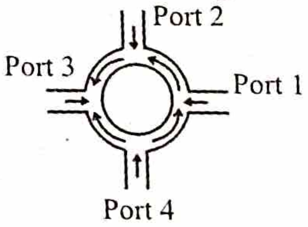
Where P and Q are + ve and real

$P^2 + Q^2 = 1$

- Coupling factor (dB) = $10\log_{10}\left(\frac{P_1}{P_4}\right)$
- Directivity (dB) = $10\log_{10}\left(\frac{P_4}{P_3}\right)$
- Isolation (dB) = $10\log_{10}\left(\frac{P_1}{P_3}\right)$
- Isolation (dB) = Directivity (dB) + Coupling factor(dB)
- The ideal value of isolation factor and directivity is infinite because of back power (P_b) zero.

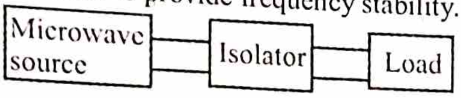
■ **Circulators:** Circulator is a passive, non reciprocal and three or four port devices.

- That uses the property of faraday rotation in the ferrite materials.
- It is n-port unidirectional waveguide.


Port 2
Port 3
Port 1
Port 4

- S-matrix of circulators, $S = \begin{bmatrix} 0 & 0 & 0 & 1 \\ 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \end{bmatrix}$

- **Isolators :**
  - It is a 2-port device.
  - It provides small amount of attenuation in forward direction but maximum attenuation in reverse direction.
  - It is used to provide frequency stability.



  - S-matrix for isolators, $S = \begin{bmatrix} 0 & 0 \\ 1 & 0 \end{bmatrix}$
  - It is also called uniline.

- **Microwave transistor and tunnel diode :**

- **Microwave Transistor:** Microwave Transistor is a non-linear device.
  - Its principle of operation is similar to that of low frequency device.
- **Advantage of Microwave Transistor-**
  - Small size
  - Low power dissipation
  - Good efficiency

- **Power frequency limitation of microwave power transistors.**

- **Voltage Frequency limitation :**

$$\boxed{V_{MFT} = \frac{E_m V_s}{2\pi}\begin{Bmatrix} 2\times10^{11}\,V/s & (\text{for Si}) \\ 1\times10^{11}\,V/s & (\text{for Ge}) \end{Bmatrix}}$$

Where,

$f_T = \frac{1}{2\pi\tau}$ is the charge carrier transmit time cut off frequency.

$\tau = \frac{L}{V}$ is the average time.

$V_m = E_m L_{min}$ is the maximum applied voltage.

E_m = Maximum electric field.

- **Current frequency limitation** $\boxed{(I_m X_c) f_T = \frac{E_m V_s}{2\pi}}$

- **Power gain frequency limitation -**

$$\boxed{(G_m V_{th} V_m)^{\frac{1}{2}} . f_T = \frac{E_m V_s}{2\pi}}$$

Where,

G_m = Maximum available power gain

$V_{th} = \frac{kT}{q}$ is the thermal voltage

k = Boltzmann's constant

T = absolute temperature in Kelvin.

- **Power frequency limitation :**

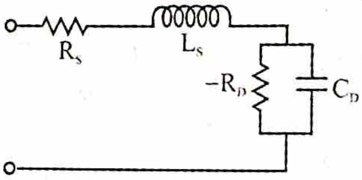
$$\boxed{(P_m X_c)^{1/2} f_T = \frac{E_m V_s}{2\pi}}$$

- **Maximum Available power gain of Transistor :**

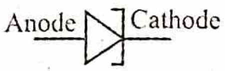
$$\boxed{G_m = \left(\frac{f_T}{f}\right)^2 \times \frac{Z_{out}}{Z_{in}}}$$

- **Homo junction Bipolar Transistor**
  - When the transistor's junction is joined by two similar materials such as silicon to silicon or Ge to Ge is called homo junction bipolar transistor.
- **Hetro junction Bipolar Transistor :**
  - The transistor junction is formed by two different materials such as Ge to GaAs is called hetro junction transistor.
- **Tunnel diode**
  - The Tunnel diodes are useful in many circuit application in microwave application, microwave oscillators and also microwave amplifier.

Equivalent ckt of Tunnel diode.



symbol of Tunnel diode



- **The input impedance Z_{in} of equivalent circuit :**

$$\boxed{Z_{in} = R_S + j\omega L_s + \frac{R_n[j/\omega C]}{-R_n - j/\omega C}}$$

Where,

R_s, L_s is inductance and resistance of packaging circuit of Tunnel diode.

R_n - Negative resistance of Tunnel diode.

C - Junction capacitance of Tunnel diode.

- **Resistive cut off frequency :**

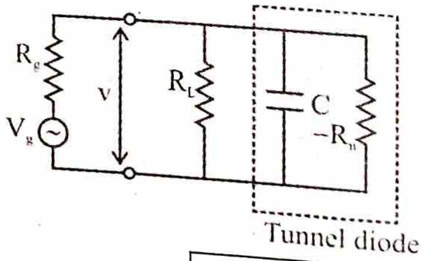
$$\boxed{f_c = \frac{1}{2\pi R_n C\sqrt{\frac{R_n}{R_s} - 1}}}$$

- **Self Resonance Frequency :**

$$\boxed{f_r = \frac{1}{2\pi R_n C}\sqrt{\frac{R_n^2 C}{L_s} - 1}}$$

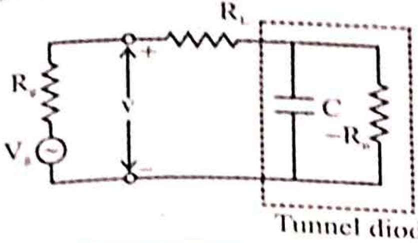
- **Parallel Loading :**

Output power in load resistance $P_{out} = \frac{V^2}{R_L}$



- Gain of tunnel diode- $\boxed{A = \frac{R_n}{R_n - R_L}}$

- **Series Loading :**


R_L
R_g
V_g
V
+
−
C
−R_n
Tunnel diode

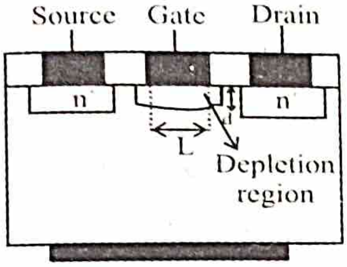
$$\boxed{A = \frac{R_l}{R_l - R_n}}$$

■ Microwave field effect transistor

- ➢ Microwave FET operates in the microwave frequencies.
- ➢ It is unipolar transistor
- ➢ It is voltage control device
- ➢ Its noise figure is low.
- ➢ Its input impedance is very high.
- ➢ Its efficiency is higher than microwave BJT.

■ Metal semiconductors field effect transistor (MESFET) :

- ➢ The metal semiconductor field effect transistor is a unipolar device because its conduction process involves predominately only one kind of carrier.


Source
Gate
Drain
n
n
L
d
Depletion region

- ➢ Mainly used material is GaAs because it has higher electron mobility.
- ➢ Its output power is greater and noise figure is low.

- **MESFET Parameters :**

- **Pinch off Voltage for MESFET** $\boxed{V_P = \frac{qN_d a^2}{2\in_s}}$
- **Velocity ratio** $\boxed{(\eta) = \frac{\mu|V_P|}{V_s L}}$
- **Cut-off-frequency** $\boxed{f_{co} = \frac{g_m}{2\pi C_{gs}} = \frac{V_S}{4\pi L}}$
- **Maximum frequency of oscillation**

$$\boxed{f_{max} = \frac{f_{CO}}{2}(g_m R_d)^{1/2}}$$

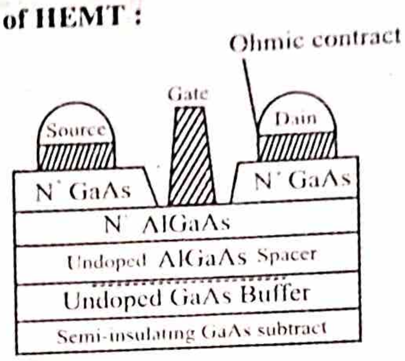
- **Highest frequency of oscillation for maximum power gain with input and output network matched.**

$$\boxed{f_{max} = \frac{f_{CO}}{2}\left(\frac{R_d}{R_S + R_g + R_i}\right)^{1/2}}$$

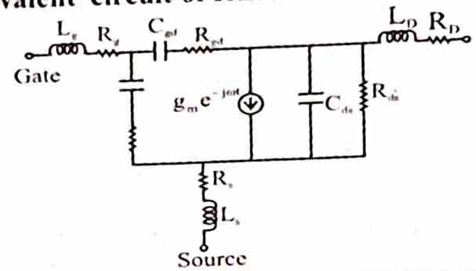
■ High Electron Mobility Transistor (HEMT) :

- ➢ It is also known as hetro structure FET (HFET) or modulation- doped FET (MODFET)
- ➢ It is generally made of GaAs with AlGaAs

- **Symbol of HEMT :**


Ohmic contract
Gate
Source
Dain
N⁺ GaAs
N⁺ GaAs
N⁺ AlGaAs
Undoped AlGaAs Spacer
Undoped GaAs Buffer
Semi-insulating GaAs subtract

- **Equivalent circuit of HEMT :**


L_g
R_g
C_gs
R_gs
L_D
R_D
Gate
g_m e^{-jωt}
C_ds
R_ds
R_s
L_s
Source

- **Drain current of HEMT:** $\boxed{I_d = qn(z)WV_{(z)}}$

n(z) = construction of two dimension electron gas

W = Gate width V(z) = Electron velocity

- **Vertical threshold sensitivity :**

$$\boxed{\frac{dv_{th}}{d\ell} = -\left[2qN_d\left(\psi_{ms} - \Delta E_C - V_{th}\right)/\in\right]^{1/2}}$$

$v_{th} \rightarrow$ Thresold voltage (v)

$\ell \rightarrow$ AlGaAs layer thickness (m)

$\psi_{ms} \rightarrow$ Metal-semiconductor schottky barrier potential between Al and GaAs.

- ➢ Normal frequency of operation for HEMTs is 50GHz-70GHz

- **Advantage:**

- ➢ It has high gain it is used in amplifier.
- ➢ It has high switching speed.
- ➢ It has low noise.

■ Charged Coupled Device (CCD)

- ➢ "Charged coupled devices" are sensors used in digital cameras, video cameras to record and moving images.
- ➢ CCD sensitivity is wide
- ➢ A typical dynamic range is about 10^5.
- ➢ It is a linear device.
- ➢ Power dissipation per bits $\boxed{P = n f VQ_{max}}$

$n \rightarrow$ number of phases,

$f \rightarrow$ Clock frequency

$V \rightarrow$ applied voltage

$Q_{max} \rightarrow$ Maximum stored charged

- **Insulator capacitance:** $\boxed{C_i = \frac{\epsilon_i}{d}}$

Where, ϵ_i = permittivity of insulator.

Transferred Electron Device (TED)

- ➢ Transferred electron device (TED) is a class of active semiconductor device used mainly for generating power in the microwave.
- ➢ They are widely used in military and commercial system.
- ➢ It is used in local oscillator, and low power radar transmitter.
- ➢ TEDs are semiconductor device with no junction and Gates.
- ➢ They are fabricated from compound semiconductor like GaAs, InP, CdTe.
- ➢ TEDs operate with hot electrons whose energy is much greater than the thermal energy.
- ➢ The negative resistance effect is due to electrons being swept from a lower valley (more mobile) region to an upper valley (less mobile) region in the conduction band.

- **Difference between microwave transistor and TED**

Microwave Transistor	TED
The microwave transistor devices are included microwave BJT, HBT, Tunnel diode etc. Electrons and holes both participate in the transport process.	TEDs devices are included Gunn diode, LSA diode and PIN diode. In this electrons transfer from lower conduction valley to upper satellite valley.
It consists of function of gates.	It does not have any function of gate, it is a bulk type of device.
It is fabricated from element semiconductor such as Ge and Si.	It is fabricated from compound semiconductor such as GaAs and InP.
It operates with low energy warm electrons.	It operates with high energy hot electrons
Application: Transmitter, L and S band high speed switching device .	**Application:** L,S, C,X band amplifier RF Transmitter and radar system.
Advantage- Low cost, Low power supply small size	**Advantage:** Low noise, high gain, Low power, light in weight.

Gunn effect :

- ➢ High frequency oscillation of electrical current flowing through certain semiconducting solids..
- ➢ The Gunn diode to produce short radio waves called microwaves. This effect was discovered by J.B. Gunn in the early 1960. It has detected only few materials GaAs.
- ➢ The reason for Gunn effect is that GaAs has two conduction band such that mobility of electron is lower in conduction band at higher energy level.

- **Gunn diode-Mode of operation:**
- ➢ Gunn oscillatory mode

$$\boxed{10^{12}/\text{cm}^2 \le n_o L < 10^{14}/\text{cm}^2}$$

$n_o L$ = Product of doping and length.

- ➢ Frequency of oscillation

$\boxed{f = \frac{V_{dom}}{L_{eff}}}$ Where, V_{dom} = Domain velocity
L_{eff} = effective length.

- **Limited space charge accumulation (LSA) Mode.**

A mode operation of a Gunn diode in which the frequency of operation is set by a resonant circuit to be much higher than the transit-time frequency so that domains have insufficient time to form while the field is above thresholds.

LSA mode is simplest mode of operation and exist for

$f_\ell > 2\times10^7$ cm/sec.

- ➢ The efficiency of LSA mode can reach up to 20%.
- ➢ For n-type GaAs $n_o L$ is about 10^{12}cm/sec.
- ➢ Oscillation period (τ_0) is several time higher than the magnitude of dielectric relation time in negative conduction region τ_d.

■ **Cd -Te Diode:** Cadmium telluride (Cd-Te) is a stable crystalline compound formed from cadmium and tellurium. It is mainly used as the semiconducting material in cadmium telluride photovoltaic and infrared optical window.

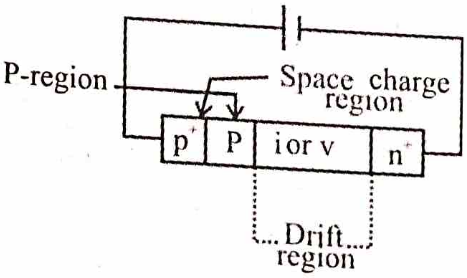
- ➢ It is also a crystal based diode works on same principle of transferred electron device but used for high frequency oscillation.

Avalanche Transit time device

- ➢ The process of having a delay between voltage and current, in avalanche together with transmit time, through the material is said to be negative resistance
- ➢ The devices that come under this category are IMPATT, TRAPATT and BARRIT diode.

Read Diode :

- ➢ It is n^+–P–i–p^+ diode.
- ➢ It consists of two regions. First is avalanche region and second is drift region



- ➢ It has very high doping.
- ➢ I or V intrinsic materials.

- Thin P region (high field/ avalanche region)- avalanche multiplication occurs.
- Intrinsic region (Drift region)- generated by holes must drift towards the p+ contact.
- Transit time of a hole across the drift (i) region of length (L) is given by-

$$\boxed{\tau = \frac{L}{V_d}}$$

- Avalanche multiplication factor $\boxed{M = \frac{1}{1-\left(\frac{V}{V_b}\right)^n}}$

Where,

V → Applied voltage

V_b→ Avalanche breakdown voltage

n → 3–6 for silicon is a numerical factor depending on the dopping of $p^+ -n$ or $n^+ -p$ function

- The break down voltage for a silicon $p^+ -n$ function.

$$\boxed{(V_D) = \frac{\rho_n \mu_n \epsilon_s |E_{max}|_b^2}{2}}$$

Where,

ρ_n → Resistivity, μ_n → Electron mobility

ε_s → Semiconductor permittivity.

- The induced current in the external circuit is

$$\boxed{I_e = \frac{V_d Q}{L}}$$

Q = Total charge of the moving holes

V_d = Hole drift velocity.

L = Length of the drift region.

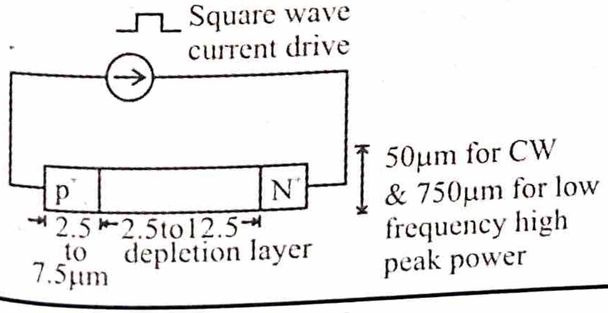
- Resonant frequency f

$$\boxed{f = \frac{V_d}{2L}}$$

TRAPATT Diode :

- The standard form of TRAPATT diode is Trapped Plasma Avalanche Triggered Transit diode.
- A microwave generator which operate between hundred of MHz to GHz
- Its structure is N^+-P-P^+ or P^+-N-N^+ with N type depletion region width varying from 2.5 to 12.5μm.
- It is high efficiency microwave generator.
- The efficiency of this diode is 20% to 60%.

- **TRAPATT Diode Figure :**


Square wave current drive
p⁺
N⁺
2.5 to 7.5μm
2.5to12.5
depletion layer
50μm for CW & 750μm for low frequency high peak power

- Avalanche zone velocity V_z

$$V_z = \frac{J}{qN_A}$$

Where,

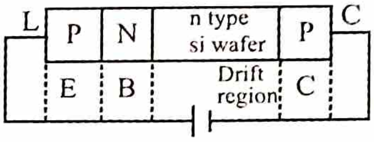
J = Current density

N_A= Doping Concentration of n - region

- **Application of TRAPATT Diode :**
- Low power Doppler radar
- Local oscillator for radar
- Radio Alternator.

BARRIT Diode :

- Full form of BARRIT diode is Barrier injection transit time diode.
- It has long drift region.
- These are latest invention in this family.
- This diode exhibits a negative resistance for transit angle π and 2π.



- **Critical voltage:** $\boxed{V_C = \frac{qNL^2}{2\in_s}}$

Where,

V_C = Critical voltage

N = Doping concentration

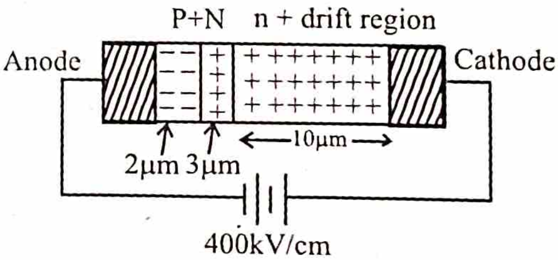
L = Semiconductor thickness

$\in_S$ = Semiconductor dielectric permittivity.

IMPATT Diode :

- This is a high power semiconductor diode.
- It is used in high frequency microwave application.
- IMPATT stand for impact ionization avalanche transit time diode.

- **IMPATT Diode symbol.**



- **Resonant frequency (Frequency of oscillations)**

$$\boxed{f = \frac{V_d}{2L}}$$

Where,

V_d = Carrier drift velocity

L = drift region length

- **The efficiency of IMPATT diode**

$$\eta = \left(\frac{V_a}{V_d}\right)\left(\frac{I_a}{I_d}\right)$$

V_d, I_d = DC voltage and DC current

V_a, I_a = AC voltage and AC current

➢ Efficiency of this diode is near about 30%

- **Application :**

➢ Microwave oscillator.

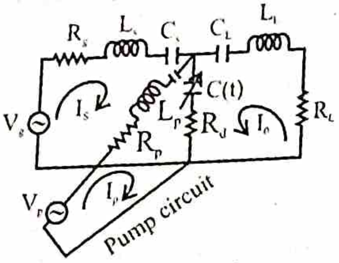
➢ Microwave generator.

➢ Modulated output oscillator.

➢ Receiver local oscillator.

➢ Negative resistance amplification.

■ Parametric Amplifiers :



➢ A parametric device is one that uses a non-linear reactance or a time varying reactance.

➢ A parametric amplifier circuit is generally use as negative resistance device.

➢ The heart of the line is the gallium-arsenide, variable reactance diode, which gives improved noise performance over a wide range.

➢ It is highly sensitive low noise amplifier for ultra-high frequency and microwave radio signal.

- **Output frequency :**

$$\boxed{f_0 = mf_p \pm nf_s}$$

m, n are + (Ve) integer

f_s = Signal frequency

f_p = pump frequency

f_0 = output frequency

➢ When $f_0 > f_s$ the device is called parametric up-converter.

➢ $f_0 < f_s$ then parametric down converter.

- **Difference between parametric up converter and parametric down converter :**

Parametric UP converter	**Parametric down converter**
Output frequency is sum of signal frequency and pump frequency.	Signal frequency f_s must be equal to the sum of the pump frequency and output frequency.
$f_0 > f_s$ then it is called parametric up converter	$f_0 < f_s$ then it is called parametric down converter.
Power gain of parametric up converter is $\text{Gain} = \frac{f_0}{f_s} \times \frac{x}{\left(1+\sqrt{1+x}\right)^2}$ where $f_0 = f_s + f_p$ $x = \frac{f_s}{f_0}(\gamma Q)^2$ $Q = \frac{1}{2\pi f_s C R_d}$	3. Gain of parametric down converter $\boxed{\text{Gain} = \frac{4f_i}{f_s}\frac{R_g R_i}{R_{TS} R_{Ti}}\frac{a}{(1-a)^2}}$ $f_i =$ $f_p - f_s$ is the idler frequency R_g = output resistance of the signal generator. R_i = output resistance of idler generator R_{TS} = Total series resistance at f_s R_{Ti} = Total series resistance at f_i $a = \frac{R}{R_{TS}}$ $R = \gamma^2/\omega_s\omega_i c^2 R_{Ti}$
Noise figure $F = 1 + \frac{2T_d}{T_0}\left[\frac{1}{\gamma Q} + \frac{1}{(\gamma Q)^2}\right]$ T_d = Diode Temp. T_0 = 300°K is the ambient temp γQ = figure of merit for non linear capacitor	**Noise figure** $F = 1 + \frac{2T_d}{T_0}\left[\frac{1}{\gamma Q} + \frac{1}{(\gamma Q)^2}\right]$

■ Microwave Linear beam tube

➢ Linear beam tubes are the most versatile device used for the generation and amplification of energy at microwave frequencies. Ex- Klystron and TWT.

➢ Klystron and TWT linear beam are O type tube in which the accelerating electric field in the same direction as the static magnetic field used to focus the electron beam.

➢ O type travelling wave tubes are suitable for amplification.

- **Microwave tube-** Microwave tubes are used for amplification and generation at microwave frequency.

1. Klystron amplifier [Two cavity, multicavity]
2. Klystron oscillator [Reflex klystron]
3. Travelling wave Tube Amplifier (TWT)

■ **Klystrons:** A klystron is a vaccum tube that can be used as a generator amplifier of a microwave frequency

- Klystron's operation is based on the principle of velocity modulation.
- **Two cavity klystron amplifier :**

➢ Two cavity klystron can be used for amplification of microwave signal.

- **Tube circuit :**

$$\boxed{\text{High velocity } e^- \text{ beam formation}} \rightarrow \boxed{\text{Focusing three beam}} \rightarrow \boxed{\text{send through the glass tube}}$$

- ➢ Electron beam is sent from input cavity (buncher) to output cavity (catches) through a field free space and finally sent to collector.

- **Performance :**
- ➢ Frequency 250MHz to 100 GHz [60 GHz Normal]
- ➢ Power 100 KW-500 KW
- ➢ Power gain 15 dB-70dB [60dB Normal]
- ➢ Noise figure [15-20dB]
- ➢ Efficiency 58%
- **Applications :**
- ➢ In UHF TV transmitters
- ➢ Satellite communication, Ground satellite
- ➢ Radar transmitter

■ Velocity Modulation Process :

- **Velocity of e^- due to high dc voltage**

$$V_0 = \sqrt{\frac{2qV_0}{m}} = 0.593\times10^6\sqrt{V_0}\,m/s$$

- **Average transit time through buncher gap distance**

$$\boxed{\tau = \frac{d}{V_0}(t_1 - t_0)}$$

Where, t_0 = time at which e^- enters from buncher gap

- **Average gap transit angle**

$$\boxed{\theta_g = \omega_\tau = \omega(t_1 - t_0) = \frac{\omega d}{V_0}}$$

- **Average microwave voltage in the buncher gap**

$$V_s = V_{av} = \frac{V_1 \sin\left(\frac{\omega d}{2V_0}\right)}{\left(\frac{\omega d}{2V_0}\right)}\sin\left(\omega t_0 + \frac{\omega d}{2V_0}\right)$$

$$V_{av} = V_1\frac{\sin\left(\frac{\theta_g}{2}\right)}{\left(\frac{\theta_g}{2}\right)}\sin\left(\omega t_0 + \frac{\theta_g}{2}\right)$$

- **Beam coupling coefficient**

$$\beta_i = \frac{\sin\left(\frac{\omega d}{2V_0}\right)}{\frac{\omega d}{2V_0}} = \frac{\sin\left(\frac{\theta_g}{2}\right)}{\left(\frac{\theta_g}{2}\right)}$$

- **Bunching process :** Maximum and minimum velocity of e^- exit from buncher cavity is -

$$\boxed{V_{max} = V_0\left[1 + \frac{\beta_i V_1}{2V_0}\right]}, \boxed{V_{min} = V_0\left[1 - \frac{\beta_i V_1}{2V_0}\right]}$$

- **Induced current:** Magnitude of fundamental component of induced current at catcher cavity is

$$\boxed{I_{2ind} = \beta_0 2I_0 J_1(x)}$$

β_0= Beam coupling coefficient of catcher cavity, if buncher and catcher cavity are identical then $\beta_i = \beta_0$

- **Output power :**

$$\boxed{P_0 = \frac{(\beta_i I_f)^2}{2}R_{Sho} = \frac{\beta_0 I_f V_2}{2}}$$

- **Efficiency**

$$\boxed{\eta = \frac{P_{out}}{P_{in}} = \frac{\beta_0 I_f V_2}{2I_0 V_0}}$$

- **Input voltage of bunching parameter**

$$\boxed{V_i = \frac{2V_0}{\beta_0\theta_0}x}$$

- **Voltage gain of klystron amplifier**

$$\boxed{A_V = \frac{V_2}{V_1} = \frac{\beta_0 I_f R_{Sho}}{V_i} = \frac{\beta_0^2\theta_0}{R_0}\frac{J_1(x)}{x}R_{sho}}$$

➢ $\boxed{A_V = G_m R_{Sh0}}$

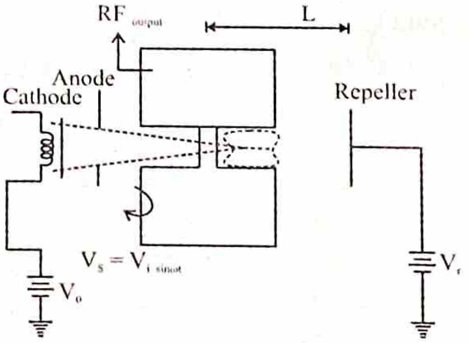
- **Loaded quality factor of the catcher cavity**

$$\boxed{\frac{1}{Q_L} = \frac{1}{Q_0} + \frac{1}{Q_B} + \frac{1}{Q_{ext}}}$$

Where,
Q_L = Loaded quality factor whole catcher cavity
Q_0 = Quality factor of the catcher wall
Q_B = Quality factor of the beam loading
Q_{ext} = Quality factor of external load

■ Reflex klystron:

- ➢ Reflex klystron is single cavity variable frequency generator of low power and low frequency.
- **Applications :**
- ➢ In Radar receiver
- ➢ Local oscillator in microwave receiver
- ➢ Signal source in μ-wave generator of variable frequency.
- ➢ Pump oscillator in parametric Amplifier.



- ➢ It consists of an electron gun, A filament surrounded by cathode, focusing electrode and a repeller.

- The time taken by e⁻ to go to the repeller electrode and come back to repeller space till sustaining oscillation is known as transit time.

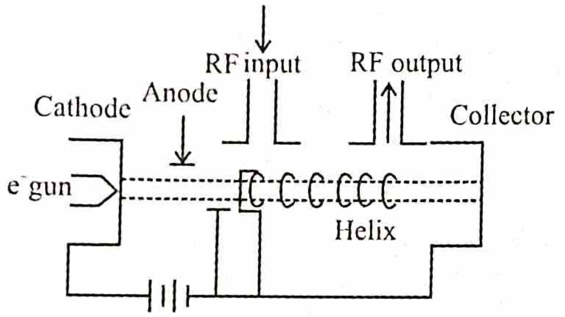
$$\boxed{T = \eta + \frac{3}{4}}$$

Where n = an integer

- **Performance of Reflex Klystron**
- Frequency range 4 to 200 GHz
- Output power 1mW to 2.5W
- Efficiency 22.78%.
- Tuning range → 5 GHz at 2W to 30 GHz at 10 MW

Travelling Wave Tube (TWT):

- This is a new type of microwave tube which plays on important role in broad band amplifier.
- **Figure of TWT :**



- TWT also consists of an electron gun, which forms an electron beam of constant velocity narrow.
- Electron beam posses from the centre of long axial helix
- The amplified output signal is taken from the other terminal of helix, at perfect operating conditions.
- **Performance characteristics of TWT :**
- Frequency of operation 0.5GHz to 95 GHz
- Efficiency → 5 to 20%
- Noise figure → 4-6 dB (Low power TWT)
  25 dB (High power TWT)
- **Application :**
- Low noise RF amplifier
- Repeater amplifier
- Power output tube in satellite
- Gain parameter of TWT

$$\boxed{C = \left(\frac{I_0 Z_0}{4V_0}\right)^{1/3}}$$

I_0 = DC current or beam current

V_0 = Beam voltage or DC voltage

Z_0 = Characteristic impedance of helix

- Output power gain A_P in decibel

$$\boxed{A_{p(dB)} = -9.54 + 47.3NC}$$

- The value of propagation constant

$$\boxed{\gamma_1 = -\beta_e C\frac{\sqrt{3}}{2} + j\beta_e\left(1+\frac{C}{2}\right)}$$

$$\boxed{\gamma_2 = \beta_e C\frac{\sqrt{3}}{2} + j\beta_e\left(1+\frac{C}{2}\right)} \qquad \boxed{\gamma_3 = j\beta_e(1-C)}$$

$$\boxed{\gamma_4 = -j\beta_e\left(1-\frac{C^3}{4}\right)}$$

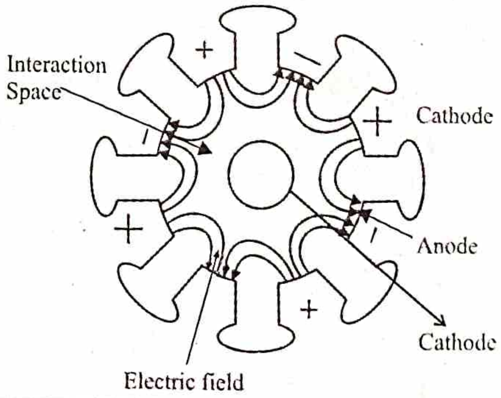
Backward wave oscillator :

- BWO is a short and thick TWT.
- The construction of BWO similar to TWT and BWO is a continuous wave oscillator which twinning capacity and frequency coverage is excellent.
- **Performance of BWO**
- Frequency range 1GHz to 1000 GHz
- Power output 10MW to 150MW
- Twinning range upto 40GHz
- **Application of BWO**
- Signal source in instruments and transmitter
- Noiseless oscillator.

Microwave Cross Field tubes (M-types)

- **Introduction:** There are basically two types of vaccum tube-
- 1. Linear Beam tube (TWT and klystron)
- 2. Cross field tube (Magnetrons)
- **Cross field tube**-it is also called m-type tubes, A CFA has lower gain and bandwidth than other microwave amplifier tubes (such as klystrons or traveling-wave tubes); but it is more efficient and capable of much higher output power.
- In cross field tube, the dc magnetic field plays a direct role in the RF interaction process.

Magnetron : Magnetron is a grouping of a simple diode vaccum tube together with built in cavity resonator and exceptionally powerful magnet.



- **There are three types of magnetron-**
- Negative resistance type.
- Cyclotron frequency type.
- Travelling wave or cavity tube.

- **Cylindrical Magnetron:** It is a diode usually of cylindrical configuration with a thick cylindrical cathode at the center and a coaxial cylindrical block of copper as anode.

➢ DC voltage is applied between cathode and anode.

- **Hull cutoff magnetic equation** $$\boxed{B_{OC} = \frac{\left(\frac{8V_0 m}{q}\right)^{1/2}}{b\left(1-\frac{a^2}{b^2}\right)}}$$

Where,
V_0 = DC Voltage
a = Radius of cathode cylinder
b = Radius from the centre of cathode to the edge to the anode.

- **Hull cut-off voltage** $$\boxed{V_{oc} = \frac{q}{8m}B_0^2 b^2\left(1-\frac{a^2}{b^2}\right)^2}$$

B_0 = applied magnetic flux.

- **Cyclotron angular frequency** $$\boxed{\omega_C = \frac{q}{m}B_0}$$

ω_C = Cyclotron angular frequency
m = mass of electron
B_0 = Applied magnetic flux density.

- **Time period of one complete revolution**

$$\boxed{T = \frac{2\pi}{\omega_C} = \frac{2\pi m}{qB_0}}$$

- **The phase shift between two adjacent cavities is-**

$$\boxed{\phi_n = \frac{2\pi p}{N}}$$

Where p - is an integer.

➢ Total phase shift around the structure is the integral multiple of 2π.

➢ Magnetron oscillator are ordinary operated in π mode.

➢ Phase constant of fundamental mode field is-

$$\boxed{\beta_0 = \frac{2\pi p}{NL}}$$

Where, $\beta_0 \rightarrow$ Phase constant

Microwave Measurement

➢ Parameters which can be measured at microwave are- frequency, power, attenuation VSWR, impedance, noise factor, and insertion losses.

➢ There are many measurement devices used in microwave frequency like, spectrum analyzer, network analyzer, wave meter, power meter, VSWR meter, tunable detectors and slotted line.

- **Power Measurement :**

➢ Basically, microwave power can be measured by the combination of a power detector and a power meter.

➢ Bolometer is a device which is used for low microwave power measurement.

- **VSWR Measurement :**

➢ Ratio of maximum to minimum voltage on a transmission line is called VSWR.

$$\boxed{VSWR = \frac{V_{max}}{V_{min}} = \frac{1+\rho}{1-\rho}}$$

Where $\rightarrow \rho$, Reflection coefficient.

➢ Double minimum method is used for measuring

VSWR > 10 $\boxed{VSWR = \frac{\lambda g}{\pi(d_2 - d_1)}}$

- **Frequency measurement :** The frequency measurement of the microwave, can be measured by both mechanical and electronic technique.

➢ **Electronic Technique :** Generally this technique is used for measurement of frequency because it gives more accurate result but this technique is too expensive.

- **Attenuation Measurement :** Attenuation is the ratio of input power to the output power.
it is expressed in (dB).

$$\text{Attenuation (in dB)} = 10\log_{10}\left(\frac{P_{in}}{P_{out}}\right)$$

- **Measurement of noise factor and noise figure.**
Noise factor is the ratio of S/N ratio of input ratio of output-

$$\text{Noise Factor} = \frac{\text{SNR at input}}{\text{SNR at output}}$$

Noise Figure (F), decibel value of noise factor.
F = 10 $\log_{10}$ [Noise Factor]

Micro Strip line:

Micro strip lines are used to convey microwave- frequency signals.

➢ Micro strip is an electrical transmission line which can be fabricated with any technology a conductor is separated from ground plane by a dielectric layer known as the substrate.

- **Dielectric losses:-** This loss occurs due to different insulating materials used as space, or plastic covers $\boxed{P = 2\pi f c V^2 \tan\theta}$

- **Insertion Losses :-** It is measure of energy loss through the transmission line as compared to direct transmission of energy without transmission.

$$\boxed{\text{Insertion loss (dB)} = 10\log_{10}\left[\frac{E_1}{E_2}\right]}$$

➢ Intrinsic impedance of a free space- 377Ω.

MICROPROCESSOR 8085, 8086 & MICROCONTROLLER

Note :

- **1-bit = 1/0**
- **1-nibble = Group of 4-bit**
- **1-byte = 8-bit = 2-Nibble**
- **1-kB = 1024-byte = 2^{10}-byte**
- **1-MB = 1024 kb = 2^{20}-byte**
- **1-GB = 1024 MB = 2^{30}-byte**
- **1-TB = 1024 GB = 2^{40}-byte**

❑ Computer languages

1. Machine language-

➢ A program written in terms of 1's & 0's is called machine language

➢ It is very fast

➢ It is machine dependent

➢ In machine language, it is difficult to modify errors

2. Assembly language-

➢ If a program is written in English then like those word is called mnemonics and the language is called assembly language

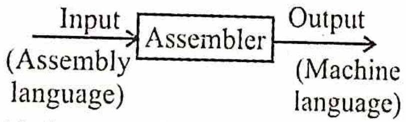
Ex. MOV, MVI, LDA etc

3. High level language-

➢ HLL is machine independent language

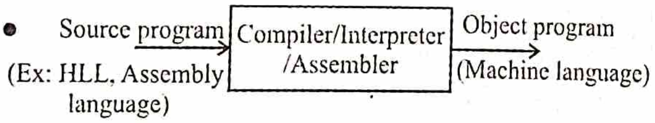
Ex. C, C^{++}, JAVA, COBOL, FORTRAN etc.

■ Assembler-

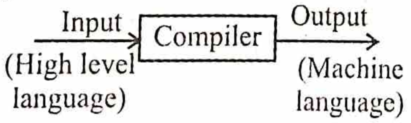

Input
Assembler
Output
(Assembly language)
(Machine language)

➢ Assembly language is machine dependent language

➢ Machine language and Assembly language are low level language


Source program
(Ex: HLL, Assembly language)
Compiler/Interpreter /Assembler
Object program
(Machine language)

■ Compiler-


Input
Compiler
Output
(High level language)
(Machine language)

➢ Compiler is a program which translates HLL into machine language and read the entire program then execute.

➢ It is faster than interpreter.

■ Interpreter-

➢ Interpreter which translate the HLL into machine language execute it and read one statement at a time and then goes to next statement of the program.

➢ It is occupied less memory space than compiler.

- **Loader-** The loader is a program that load the secondary memory of program into the main memory.
- **Linker-** A linker is a special program, which links (combined) a small program as for single program.
- **Firmware-** A software program is stored in a ROM that can not be changed is known as firmwave.
- **Hardware-** Physical components of systems are called Hardware
- **Program-** Set of instruction
- **Software-** Group of program
- **Instruction-** It is a binary pattern.

❑ Microprocessor

Microprocessor	Word length	Memory capacity
Intel 4004 (PMOS)	4-bit	640 B
Intel 8008 (NMOS)	8-bit	16 KB
Intel 8080 (NMOS)	8-bit	64 KB
Intel 8085 (NMOS)	8-bit	64 KB
Intel 8086 (HMOS)	16-bit	1 MB
Intel 8088 (HMOS)	8/16-bit	1MB
Intel 80186(HMOS)	16-bit	1 MB
Intel 80286(HMOS)	16-bit	16 MB real, 4 GB Virtual
Intel 80386(HMOS)	32-bit	4 GB real, 4 GB Virtual
Intel 80486(HMOS)	32-bit	4 GB real, 64 TB Virtual
Pentium-II	64-bit	64 GB Real
Z-80	8-bit	64 KB
Z-800	8-bit	500 KB

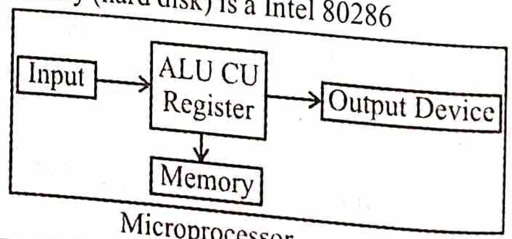
Note:

➢ A microprocessor is a multipurpose clock driven, register based electronics device.

➢ Microprocessor contains ALU, control units and register of a CPU in a single package.

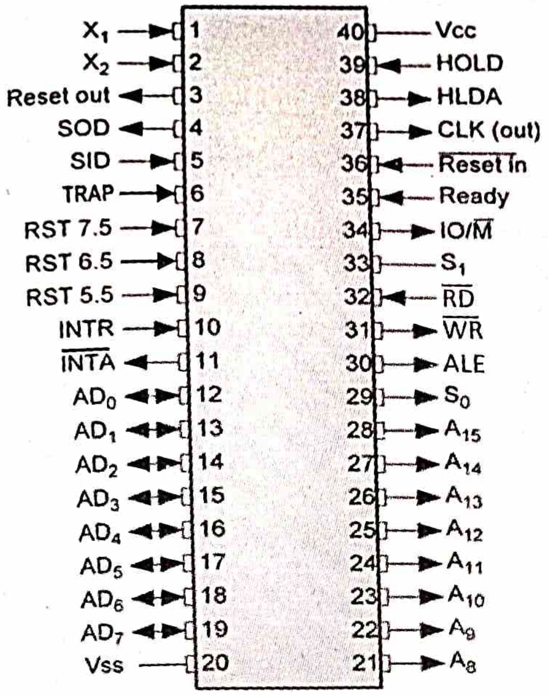
➢ Instruction set of 8080+RIM+SIM= Instruction set of 8085.

➢ First microprocessor which support the secondary memory (hard disk) is a Intel 80286


Input
ALU CU Register
Output Device
Memory

Microprocessor

8085 Microprocessor :



X_1
X_2
Reset out
SOD
SID
TRAP
RST 7.5
RST 6.5
RST 5.5
INTR
$\overline{INTA}$
AD_0
AD_1
AD_2
AD_3
AD_4
AD_5
AD_6
AD_7
Vss
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
40
39
38
37
36
35
34
33
32
31
30
29
28
27
26
25
24
23
22
21
Vcc
HOLD
HLDA
CLK (out)
$\overline{Reset\ In}$
Ready
IO/$\overline{M}$
S_1
$\overline{RD}$
$\overline{WR}$
ALE
S_0
A_{15}
A_{14}
A_{13}
A_{12}
A_{11}
A_{10}
A_9
A_8

☞ Remember point

- ➢ It is 8 bit processor (e.g. word length = 8 bit)
- ➢ It is manufactured from NMOS technology
- ➢ Address bus : It is unidirectional (16 bit address line)
- ➢ Data bus : It is bidirectional (8 bit data bus line)
- ➢ Maximum memory that can interface with 8085 = 65536 bytes (64 K bytes)
- ➢ $AD_7 - AD_0$ → Multiplexed address and data bus
- ➢ A_{15} - A_8 → Address bus
- ➢ Clock frequency is 3 MHz
- ➢ It can access up to 64 KB
- ➢ 40 Pins (DIP) IC package
- ➢ No. of output pin/outward pin - 27
- ➢ No. of input pin/inward pin - 21
- ➢ Lower address line & data line is multiplex by TDM (Time division multiplexing)
- ➢ % of duty cycle = 50%
- ➢ It is operated with single +5V supply.

- **System bus-**

➢ Bus is group of conductor (or wire)

➢ System bus are three types-

1. Address bus-

➢ It consists of group of 16-wires, defined as A_0–A_{15}.

➢ It is unidirectional, which means that information flow only from microprocessor to memory or microprocessor to input device.

➢ It defines the memory handling capacity of microprocessor.

2. Data bus-

➢ AD_7- AD_0 are bidirectional they are used as the lower order address bus as well as the data bus.

➢ It is consists of group of 8-wires, from D_0–D_7 terminals.

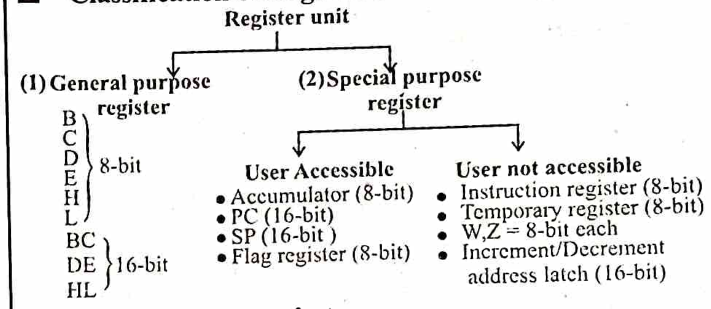
➢ It is bidirectional, which means that information flows between microprocessor to memory, microprocessor to input devices, memory to microprocessor. Input device to microprocessor.

3. Control bus-

➢ It is consists of single line which are used to control the information from microprocessor to peripherals or from peripherals to microprocessor.

➢ The control bus array and control signal are partially unidirectional or partially bidirectional.

■ Classification of Register in 8085 microprocessor



Register unit
(1) General purpose register
(2) Special purpose register
B
C
D
E
H
L
8-bit
BC
DE
HL
16-bit
User Accessible
• Accumulator (8-bit)
• PC (16-bit)
• SP (16-bit)
• Flag register (8-bit)
User not accessible
• Instruction register (8-bit)
• Temporary register (8-bit)
• W,Z = 8-bit each
• Increment/Decrement address latch (16-bit)

☞ Remember point

➢ Program Counter (PC) hold the address of next instruction to be executed.

➢ Stack Pointer (SP) is a 16-bit register which is used to point the top of stack memory (or hold the address of top of stack memory).

➢ Stack memory is the part of RAM, which is used to store the temporary data and the content of program counter when sub-routines are used.

➢ Stack is operates on the principle of LIFO (Last In First Out).

➢ Instructions Register (IR) hold the operation code (Opcode) of the instruction which the microprocessor is currently executed.

➢ IR, loaded during opcode fetch cycle.

➢ ALU = Accumulator+ Temporary register + 5-flags and Arithmetic and logical circuit.

IO/$\overline{M}$	$\overline{RD}$	$\overline{WR}$	Operation
0	0	1	Memory read $\left(\overline{MEMR}\right)$
0	1	0	Memory write $\left(\overline{MEMW}\right)$
1	0	1	I/O Read $\left(\overline{IOR}\right)$
1	1	0	I/O Write $\left(\overline{IOW}\right)$

- **Status Pin (S_1,S_0)**

➢ These are the status line which indicate the status of the operation.

S_1	S_0	Operation
0	0	HALT
0	1	Write
1	0	Read
1	1	Fetch

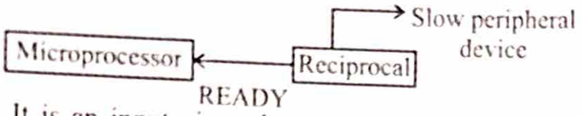
IO/$\overline{M}$	S_1	S_0	Operation
(Hi-Z)	0	0	HLT
0	0	1	Mem. Write
0	1	0	Mem. Read
1	0	1	IO Write
1	1	0	IO Read
0	1	1	Fetch
1	1	1	$\overline{\text{INTA}}$

- **ALE (Address Latch Enable)-**

➢ If ALE = 1, then AD_0-AD_7=A_0-A_7

➢ If ALE = 0, then AD_0-AD_7=D_0-D_7

- **READY PIN-**



➢ It is an input pin to known as the status of a slow peripheral device

➢ If the signal at the ready pin is low, then the microprocessor inter into a wait state T_2 and T_3.

➢ READY pin introduce wait state

➢ READY pin signal is used to synchronize slow peripheral device with microprocessor

■ **Power supply and clock frequency:**

V_{cc}	+5V Power supply.
V_{ss}	Ground reference.
X_1, X_2	A crystal oscillator is connected at these two pins. The frequency is internally divided by two using one T flip-flop therefore, To operate a system at 3MHz the crystal oscillator should have frequency of 6 MHz.
CLK (OUT)	This signal can be used as the system clock for other device.

■ **Interrupt signals :**

- **Software interrupt :**

Interrupt	Address	Interrupt	Address
RST0	0000 H	RST 4	0020 H
RST 1	0008 H	RST 5	0028 H
RST 2	0010 H	RST 6	0030 H
RST 3	0018 H	RST 7	0038 H

- **Hardware Interrupt -**

Interrupt	Triggering	Vectored/Non-Vectored Address	Maskable/ Non - Maskable	Address
TRAP	Edge and level	Vectored	Non - Maskable	0024H
RST 7.5	Edge	Vectored	Maskable	003CH
RST 6.5	Level	Vectored	Maskable	0034H
RST 5.5	Level	Vectored	Maskable	002CH
INTR	Level	Non-Vectored	Maskable	0000H-0038H

☞ **Remember point**

➢ TRAP is highest priority among all the interrupts.
➢ TRAP is also called as RST 4.5 interrupt.
➢ Priority order of interrupts are -
TRAP > RST 7.5 > RST 6.5 > RST 5.5 > INTR
➢ No. of hardware interrupt = 5
➢ No. of software interrupt = 8
➢ Total no. of interrupt in 8085 = 13

■ **Reset signals :**

$\overline{\text{RESET IN}}$	When the signal on this pin is low (0). the program counter is set to zero, the buses are tri-state and the microprocessor unit is reset. Program Counter = 0000H
RESET OUT	This signal indicates that the microprocessor is being reset. The signal can be used to reset other device.

■ **DMA Request signal**

HOLD	Hold is an active high input signal that is used by another controller to request microprocessor to use address, data and control signal.
HLDA	It is a signal which indicates that the hold request has been received after the removal of a HOLD request, the HLDA goes low.

■ **Serial I/O Ports :** Serial transmission in 8085 is implemented by the two signals.

- **SID and SOD :** SID is a data line for serial input where as SOD is a data line for output.

Note: SID & SOD are internally connected to D_7 bit of accumulator.

■ **Some important instruction of 8085 -**

The 8085 microprocessor has 74 basic instruction and 246 total instruction.

Note:

➢ The instruction word size of 8085 microprocessor can be one-byte, two-byte and three-byte.

➢ Different phases in execution process:

Input → Fetch → Decoder → Execution → Output

- **T-state:**

➢ T-state is the time period of a single clock of the clock frequency.

- Op-code fetch→4T/6T
- I/O read→3T
- Memory read→3T
- I/O write→3T
- Memory write →3T
- Bus Idle machine cycle→3T
- Interrupt acknowledge cycle→3T

Note: Special fetch cycle (6T)

C→ CALL, RET
R→ RST
I→ INX, DCX
S→ SPHL, PCHL
P→ PUSH

- **Machine cycle**

➢ The no. of T-state required to access a peripheral is called a machine cycle.

➢ Machine cycle may be consists of 3 to 6-T state.

- **Instruction cycle (IC)**

➢ Total no. of machine cycle required to fetch and execute an instruction is called IC

$$\boxed{\text{I.C.} = \text{Fetch cycle} + \text{Execute cycle}}$$

➢ Instruction cycle consists of one to five machine cycles.

➢ Maximum T-state (18-T) required for CALL instruction.

Note :- There is no separate instruction for multiplication and division in 8085.

- **Addressing Mode**

➢ The technique of specified the address of data is known as addressing mode.

- **Type of addressing mode**

Register addressing mode	Instruction specified the name of register (GPR) in which data is available.
Immediate addressing mode	The operand (or data) is given in the instruction. Ex.- MVIA, 34H,CALL, JMP etc.
Direct addressing mode	The address of data is specified in the instruction. Ex.- LDA, STA, IN, OUT, LHLD, SHLD etc.
Indirect addressing mode	The instruction specified the name of register pair in which the address of data is available. Ex.- LDAX, MOVA, M, PUSH, POP etc.
Implicit addressing mode	The instruction itself specified the data to be operated. Ex.-CMA, RAR, CMC, STC, PCHL, SPHL, DAA etc.

❑ Instructions set

Instructions	Byte	Machine cycle	T-State	Flag affected					Addressing mode
				S	Z	P	AC	CY	
MOV R, R	1	1; F	4	×	×	×	×	×	Register
MOV R, M	1	2; FR	7	×	×	×	×	×	Register indirect
MOV M, R	1	2; FW	7	×	×	×	×	×	Register indirect
MVI R, data	2	2; FR	7	×	×	×	×	×	Immediate
LXI rp, 16 bit data	3	3; FRR	10	×	×	×	×	×	Immediate
LDA address	3	4; FRRR	13	×	×	×	×	×	Direct
STA address	3	4; FRRW	13	×	×	×	×	×	Direct
LHLD address	3	5;FRRRR	16	×	×	×	×	×	Direct
SHLD address	3	5; FRRWW	16	×	×	×	×	×	Direct
LDAX rp	1	2; FR	7	×	×	×	×	×	Register indirect
STAX	1	2; FW	7	×	×	×	×	×	Register indirect
XCHG	1	1; F	4	×	×	×	×	×	Implicit
MVI M, data	2	3; FRW	10	×	×	×	×	×	Register indirect/Immediate
ADD R / ADC R	1	1; F	4	✓	✓	✓	✓	✓	Register
ADD M / ADC M	1	2; FR	7	✓	✓	✓	✓	✓	Register indirect
ADI data	2	2; FR	7	✓	✓	✓	✓	✓	Immediate
SUB R / SSB R	1	1;F	4	✓	✓	✓	✓	✓	Register
SUB M / SSB M	1	2;FR	7	✓	✓	✓	✓	✓	Register indirect
SUI data	2	2; FR	7	✓	✓	✓	✓	✓	Immediate
INR R	1	1;F	4	✓	✓	✓	✓	×	Register
INR M	1	3; FRW	10	✓	✓	✓	✓	×	Register indirect
INX rp	1	1;SF	6	×	×	×	×	×	Register
DCR R	1	1;F	4	✓	✓	✓	✓	×	Register
DCR M	1	3;FRW	10	✓	✓	✓	✓	×	Register indirect
DCX rp	1	1; SF	6	×	×	×	×	×	Register
DAA	1	1;F	4	✓	✓	✓	✓	✓	Implicit
DAD rp	1	3;F+2BI	10	×	×	×	×	✓	Register
ANA R	1	1;F	4	✓	✓	✓	1	0	Register
ANA M	1	2;FR	7	✓	✓	✓	1	0	Register indirect
ANI data	2	2; FR	7	✓	✓	✓	1	0	Immediate
ORA R	1	1;F	4	✓	✓	✓	0	0	Register
ORA M	1	2;FR	7	✓	✓	✓	0	0	Register indirect
ORI data	2	2;FR	7	✓	✓	✓	0	0	Immediate
XRA R	1	1;F	4	✓	✓	✓	0	0	Register
XRA M	1	2;FR	7	✓	✓	✓	0	0	Register indirect
XRI data	2	2;FR	7	✓	✓	✓	0	0	Immediate
CMA	1	1;F	4	×	×	×	×	×	Implicit
CMP R	1	1;F	4	✓	✓	✓	✓	✓	Register
CMP M	1	2;FR	7	✓	✓	✓	✓	✓	Register indirect
CPI data	2	2;FR	7	✓	✓	✓	✓	✓	Immediate
CMC	1	1; F	4	×	×	×	×	✓	Implicit
STC	1	1;F	4	×	×	×	×	✓	Implicit

RLC/ RCC /RAL/RAR	1	1;F	4	×	×	×	×	✓	Implicit
JMP	3	3;FRR	10	×	×	×	×	×	Immediate
Conditional JMP									
Condition met	3	3;FRR	10	×	×	×	×	×	Immediate
Condition not met	3	2;FR	7	×	×	×	×	×	Immediate
PCHL	1	1;SF	6	×	×	×	×	×	Implicit
CALL	3	5;SFRRWW	18	×	×	×	×	×	Immediate
Conditional CALL									
Condition met	3	5; SFRRWW	18	×	×	×	×	×	Immediate
Condition not met	3	2;SFR	9	×	×	×	×	×	Immediate
RET	1	3; FRR	10	×	×	×	×	×	Implicit
Conditional RET									
Condition met	1	3;SFRR	12	×	×	×	×	×	Implicit
Condition not met	1	1;SF	6	×	×	×	×	×	Implicit
RST n	1	3;SFWW	12	×	×	×	×	×	Implicit
PUSH rp	1	3; SFWW	12	×	×	×	×	×	Register indirect
POP rp	1	3; FRR	10	×	×	×	×	×	Register indirect
SPHL	1	1;SF	6	×	×	×	×	×	Implicit
XTHL	1	5;FRRWW	16	×	×	×	×	×	Implicit
IN port address	2	3;FI/O Read + I/O Read	10	×	×	×	×	×	Direct
OUT port address	2	3;FI/O Read + I/O Write	10	×	×	×	×	×	Direct
HLT	1	1;F	5	×	×	×	×	×	Implicit
NOP	1	1;F	4	×	×	×	×	×	Implicit

- **Register in 8085-** In 8085 microprocessor according to size, there are two types of registers.

➢ **1 byte register-** In 8085 the 8-bit register can store 8-bit data. B,C,D,E,H,L are 8-bit register & it can be used by programmer.

➢ **2 byte register-** In 8085 microprocessor there are 16-bit register, 16-bit address of the memory location. BC, DE, HL, SP, PC are 16-bit register in 8085 microprocessor.

➢ **Stack pointer (SP) (16-bit)** - Stack pointer contains the address of data present at the top of stack.

➢ **Program counter (PC) (16-bit)**- Program counter contains the address of next instruction which to be executed.

➢ **Temporary Register (8 bit)** - W, Z.

➢ **Instruction Register (8 bit)** - It contains opcode of the present instruction.

☞ Remember :-

Stack :-

- Part of read/write (RAM) memory.
- Use to store temporary data and also contained of PC when subroutines are used.
- Technique involved in stack for 8085 is LIFO (Last in first out).

ALU :-

- Accumulator + Temporary register + 5 Flag register + Arithmetic and logic unit (ALU).

It is an 8-bit register having 1-bit.

- Sign (S)
- Zero (Z)
- Auxiliary Carry (AC)
- Parity (P)
- Carry (CY)

Its bit position are -

D_7	D_6	D_5	D_4	D_3	D_2	D_1	D_0
S	Z	×	AC	×	P	×	CY

Sign Flag (S) -

S = 1; When content of D_7 bit of accumulator is one.

S= 0; When content of D_7 bit of accumulator is zero.

Zero Flag (Z) -

Z = 0; If the content of accumulator is non-zero.

Z = 1; If the content of accumulator is zero.

Auxiliary Flag (AC) -

AC = 1; If there is a carry from D_3 bit to D_4 (lower nibble to higher nibble).

AC = 0; otherwise.

Parity Flag (P) -

P = 1; If number of binary 1's in accumulator is Even.

P = 0; If number of binary 1's in accumulator is Odd.

Carry Flag (CY) -

CY = 1; If carry is generated.

CY = 0; If carry is not generated.

Note: Auxiliary carry flag is used by only microprocessor.

PSW (Program/Processor Status Word)

PSW (16 bit) ⇒ Accumulator + Flag register

- **Comparison between Memory Map I/O and peripheral Map I/O-**

Characteristics	Memory Map I/O	Peripheral Map I/O
Device address	16-bit	8-bit
Control signal	$\overline{MEMR}$, $\overline{MEMW}$	$\overline{IOR}$, $\overline{IOW}$
Instruction available	MOV, STA, LHLD etc.	Only IN & OUT

Data Transfer	Between any register and I/O	Only between I/O & Accumulator
Maximum no. of I/O device	65536 (64 K)	256 input or 256 output
Hardware requirement	More hardware is needed	Less hardware is needed

- **Important IC**

➢ **IC 8051→** Microcontroller

➢ **IC 8255→** PPI (Programmable Peripheral Interfacing)

➢ **IC 8259→** PIC (Priority Interrupt Controller)

➢ **IC 8279→** Keyboard

➢ **IC 8253/8254 →** Programmable Timer

➢ **IC 8237/8257 →** DMA controller

➢ **IC 8251→** USART

➢ **IC 8250→** UART

Note: IC 8251 is used for serial communication

■ **IC 8237/8257 (DMA Controller)**

➢ DMA controller is used for data transfer between memory to I/O without microprocessor

➢ It operates in 3-modes

1. **Burst or Block transfer DMA**

➢ In burst mode, a whole block of data is shared in one contiguous sequence.

➢ It is fastest DMA mode

➢ It provides the CPU inactive for associatively long periods speed of microprocessor is reduce.

2. **Single Byte Transfer DMA**

➢ In this mode single byte will be transfer in a single hold operation.

➢ It is slower than block transfer DMA but the microprocessor instruction executed speed is faster.

3. **Cycle stealing or Transparent Mode DMA**

➢ It is slowest mode.

■ **IC 8253/8254 (Programmable Timer)**

➢ It has 24 pin DIP

➢ IC 8254 3-counter

➢ A_1, A_0 (internal pin of 8254)

A_1	A_0	Selection
0	0	Counter-0
0	1	Counter-1
1	0	Counter-2
1	1	Control register

Application

- Generate an accurate time delay
- Square wave generator
- Rate Generator
- Digital one shot

■ **IC 8255 (Programmable Peripheral Interfacing)**

- It is general purpose programmable I/O device
- It is 40 pin DIP
- It has 8-bit data bus (D_0-D_7)
- It has three ports, i.e. Port-A, Port-B and Port-C
- A_0, A_1 is control signal pin.

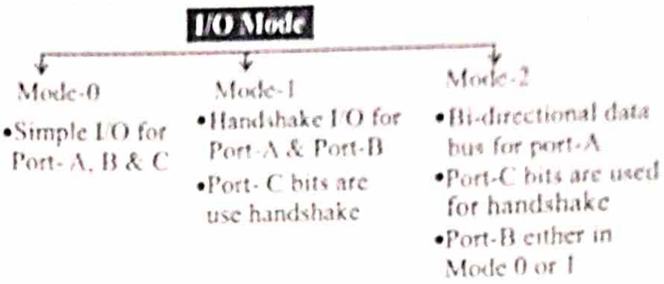
$\overline{CS}$	A_1	A_0	Selection
0	0	0	Port-A
0	0	1	Port-B
0	1	0	Port-C
0	1	1	Control register

➢ 8255 has two mode of operation

(a) BSR (Bit Set Reset) mode

(b) I/O (Input Output) mode

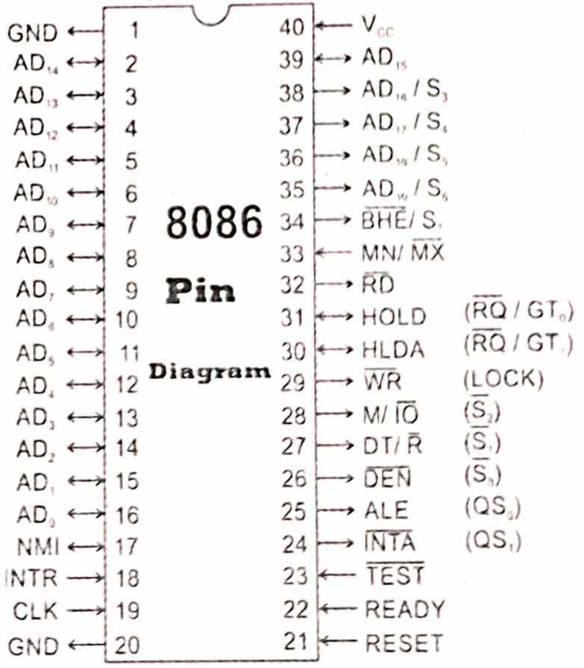
➢ BSR mode is related only with 8-bits of Port C


I/O Mode
Mode-0
•Simple I/O for Port- A, B & C
Mode-1
•Handshake I/O for Port-A & Port-B
•Port- C bits are use handshake
Mode-2
•Bi-directional data bus for port-A
•Port-C bits are used for handshake
•Port-B either in Mode 0 or 1

- **Comparison between RISC and CISC**

Reduce instruction set computer	Complex instruction set computer
Less instruction	More instruction
Less addressing mode	More addressing mode
More general purpose register	Less general purpose register
Faster	Slower
Instruction executed in one CLK period	Instruction executed more than one CLK period
Cache is more	Cache is less
Register to register operation only	Register to register, register to memory & register to I/O

- **8086 Microprocessor**


8086
Pin
Diagram
GND 1
AD14 2
AD13 3
AD12 4
AD11 5
AD10 6
AD9 7
AD8 8
AD7 9
AD6 10
AD5 11
AD4 12
AD3 13
AD2 14
AD1 15
AD0 16
NMI 17
INTR 18
CLK 19
GND 20
40 VCC
39 AD15
38 AD16 / S3
37 AD17 / S4
36 AD18 / S5
35 AD19 / S6
34 BHE / S7
33 MN/ MX
32 RD
31 HOLD (RQ / GT0)
30 HLDA (RQ / GT1)
29 WR (LOCK)
28 M/ IO (S2)
27 DT/ R (S1)
26 DEN (S0)
25 ALE (QS0)
24 INTA (QS1)
23 TEST
22 READY
21 RESET

☞ Remember point

➢ It is a 16-bit processor or 16-data lines.

➢ It has 20 address lines .

➢ In 8086 microprocessor we use H-MOS technology.

➢ Clock frequency is 5MHz to 10 MHz.

➢ For 8086, A_0-A_{15} are multiplexed with D_0-D_{15} to form AD_0-AD_{15}.

- For 8086, 16 bit data bus D_0-D_{15} (multiplexed as AD_0-AD_{15})
- Higher order address line (A_{16}-A_{19}) are also multiplex with status signal.
- It can access up to 1 MB.
- It has 40 pin DIP
- +5 Volt power supply
- Percentage of duty cycle is 33.33%
- 8086 microprocessor provides fourteen, 16-bit register.
- 8086 microprocessor uses pipelining.
- To speed the execution, 8086 microprocessor includes two processing unit called
  (1) Bus interface unit (BIU)
  (2) Execution unit
- BIU fetch the instruction and put them in a Queue and the execution unit continuously execute them unit the queue is empty.
- Queue operate on the principle of FIFO

Pipelining

- Fetching of the next instruction while the current instruction is being executed is called pipelining.
- Pipeline technique, improves the maximum clock frequency.
- 8086 microprocessor can pre-fetch to six instruction byte from the memory.

- **Flag Register**

- It is a 16-bit register having 1-bit.
- Overflow (O) Flag
- Interrupt (I) Flag
- Sign (S) Flag
- Zero (Z) Flag
- Auxiliary Carry (AC) Flag
- Direction (D) Flag
- Trap (T) Flag
- Parity (P) Flag
- Carry (CY) Flag
- Its bit position are -

D_{15}	D_{14}	D_{13}	D_{12}	D_{11}	D_{10}	D_9	D_8	D_7	D_6	D_5	D_4	D_3	D_2	D_1	D_0
×	×	×	×	O	D	I	T	S	Z	×	AC	×	P	×	CY

Overflow Flag (O) -
O = 1; If overflow is occurs.
O = 0; If overflow is not occurs.

Direction Flag (D) -
D = 1; Auto decrement.
D = 0; Auto increment.

Interrupt Flag (I) -
I = 1; Enable interrupt.
I = 0; Disable interrupt.

Trap Flag (T) -
T = 1; Perform single stepping.
T = 0; Do not perform single stepping.

Sign Flag (S) -
S = 1; When content of D_7 bit of accumulator is one.
S= 0; When content of D_7 bit of accumulator is zero.

Zero Flag (Z) -
Z = 0; If the content of accumulator is non-zero.
Z = 1; If the content of accumulator is zero.

Auxiliary Flag (AC) -
AC = 1; If there is a carry from D_3 bit to D_4 (lower nibble to higher nibble).
AC = 0; Otherwise.

Parity Flag (P) -
P = 1; If number of binary 1's in accumulator is Even.
P = 0; If number of binary 1's in accumulator is Odd.

Carry Flag (CY) -
CY = 1; If carry is generated.
CY = 0; If carry is not generated.

☐ Important Pins of 8086:

GND (Pin 20 & Pin 1)	There are two pins connected to ground
V_{CC} (Pin 40)	This pin is connected to power supply +5V DC.
RESET (Pin-21)	This is active high input signal to reset the system.
READY (Pin 22)	This is an active high input signal indicating that peripheral is ready.
$AD_0 - AD_{15}$	Bidirectional latched address data lines.
$AD_{16} - AD_{19}$	Higher order address bus
$\overline{RD}$	This is an active low output signal used for read operation
$\overline{BHE}/S_7$	Bus high enable/ status.
$MN/\overline{MX}$	This pin decide whether the processor is operating in minimum mode or maximum mode
NMI	Non- maskable interrupt request.
$\overline{TEST}$	It is an active low signal when it is low microprocessor continues execution and when it is high microprocessor goes to wait state.
Pin 2 to pin 6	There are status signals multiplexed with higher order of address line.

- **Operating modes of 8086**

(i) **MN or Min mode:**

- In this 8086 is the only processor in the system. In a minimum mode 8086 system
- 8086 is operated in minimum mode when MN/MX' pin to logic 1.

(ii) **MX or Max mode:**

- 8086 max mode is basically for implementation of allocation of global resources and passing bus control to other coprocessor (i.e. second processor in the system), because two processors can not access system bus at same instant.

(1) Addressing mode of 8086-

- **Immediate addressing mode:** In this mode the operand is specified in the instruction itself e.g. MOV BX, 3598H.

- **Direct Addressing Mode:** In this mode offset is given in the instruction as an 8 bit or 16 bit displacement. e.g. ADD BL, [0103]
- **Register Addressing Mode:** In this mode the operand is placed in one of 8 bit or 16-bit general purpose register. eg. MOV, AX, CX;
- **Register Indirect Addressing:** The operand offset is placed in one of the register such as BX, Base pointer, source index or destination register. e.g. MOV, BX.
- **Register Relative Addressing mode:** The operand offset is the sum of 8 bit or 16-bit displacement and the content of base register or base pointer eg. MOV, CL, [BX + 05H]
- **Based Index Addressing Mode:** The operand offset is the sum of content or base register and indexed register.
  offset = [B or BP] + [SI or DI]
  e.g. ADD CX, [BX + SI]
- **Relative Based Indexed Addressing Mode:** In this mode operands offset is given as offset = base register + indexed register + 8 bit or 16 bit displacement
  e.g. MOV AX, [BX + SI + 1234H]

2. Data copy/Transfer instruction:

- **PUSH Source:** Move the content from source to stack memory. Source can be register, segment register or memory. e.g. PUSH DS
- **POP Destination:** Move the content from the top of stack to destination. Destination can be register, segment register or memory.
  e.g. POP [5000H]
- **MOV Destination, Source:** Source can be register, memory location or immediate data.
  e.g. MOV CX, [037A H]
  MOV BX, [0301H]

3. Arithmetic instruction:

- **ADD Destination, Source:** Add the content of the source to destination and result is kept in destination AX is default register.
- **ADC Destination source:** Similar to ADD but adds content of carry flag also.
- **MUL, Source:** Multiplies the content to the source and content of register A
  e.g. MUL CL (Multiplies AL & CL)
- **DIV Source:** Divides the content of AL/AX register by content of source.
  e.g. DIV, CX
  DIV, [BX]
- **SUB Source:** Subtracts the content of source from AX/AL.
  e.g. SUB AX, CX

4. Logical Instruction: Logical instruction in 8086 includes AND, OR, XOR, NOT, other logical instruction are rotate instruction and shift instruction.

5. Branching Instructions: Branching instruction includes JMP, Conditional Jump, CALL, RET.

6. Interrupt Instruction: Interrupt instruction includes instruction for software interrupt.

7. LOOP Instruction: These can be conditional or unconditional loop
e.g. LOOP, LOOPZ, LOOPNZ.

- **There are 9 flags in 8086**

Data (Status) flags → S, Z, AC, P, CY, O
Control flags → D, I, T

- **Register of 8086**

General purpose register : AX, BX, CX, DX
Pointer and index register : SP, BP, SI, DI, IP
Segment register : CS, DS, SS, ES

- Accumulator (AX) Base Register (BX)
  Counter Register (CX) Data Transfer Register (DX)
  Stack Pointer (SP) Base Pointer (BP)
  Source Index (SI) Destination Index (DI)
  Code Segment Register (CS)
  Instruction Pointer (IP)
  Data Segment Register (DS)
  Stack Segment Register (SS)
  Extra segment Register (ES)

■ **Interrupt in 8086**

➢ Total interrupt of 8086 microprocessor is 256 and such as:

Type 0 : Divide by zero interrupt
Type 1 : Single stepping interrupt
Type 2 : NMI
Type 3 : Break point interrupt
Type 4 : Over flow interrupt
|
|
|
Type 255:

➢ **Priority of Interrupt**

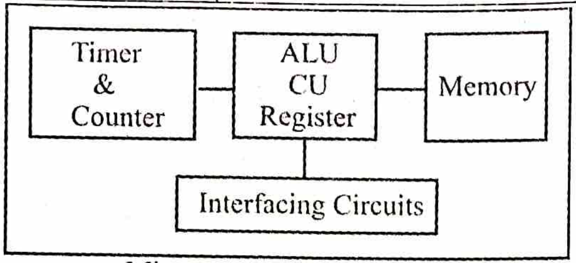
Divide by zero>NMI>INTR>Single step interrupt

■ **8051 Microcontroller :**

- **Difference between Microprocessor and Microcontroller :**

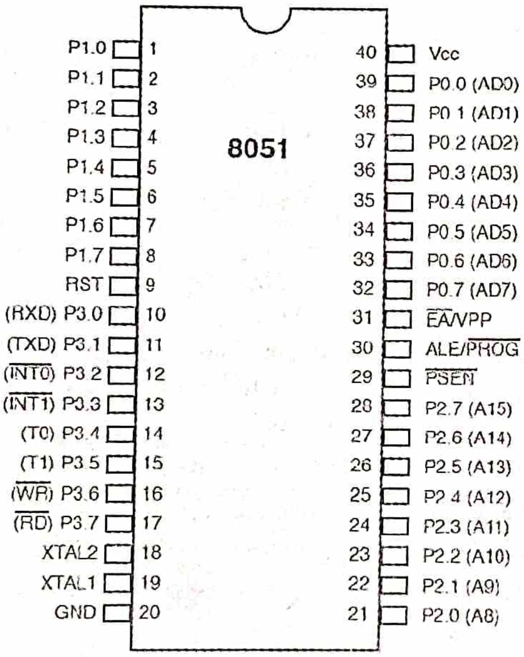
Microprocessor	**Microcontroller**
Microprocessors are designed to be used as the CPU of general purpose computers.	Microcontrollers are special purpose digital computers requires few external component for their working.
Microprocessor contains an ALU, general purpose registers, control and interrupt circuits, in one chip.	Microcontrollers have all these as well as timers, I/O ports, RAM and ROM on the chip.
Microprocessor requires many components such as, RAM, ROM etc for their working.	Many microcontroller requires no external component for their working as all these components are built onto the microcontroller chip.

Microprocessors have higher speed, greater data handling capacity and can address large amounts of memory. e.g. 8085, 8086 etc.	Microcontrollers have RAM, ROM built on same chip. Since the microcontroller are designed for use in machine such as a control device, they have slower speed and lesser address memory. e.g. 8051


Timer & Counter
ALU CU Register
Memory
Interfacing Circuits

Microcontroller Block Diagram

- **Pin Diagram –**

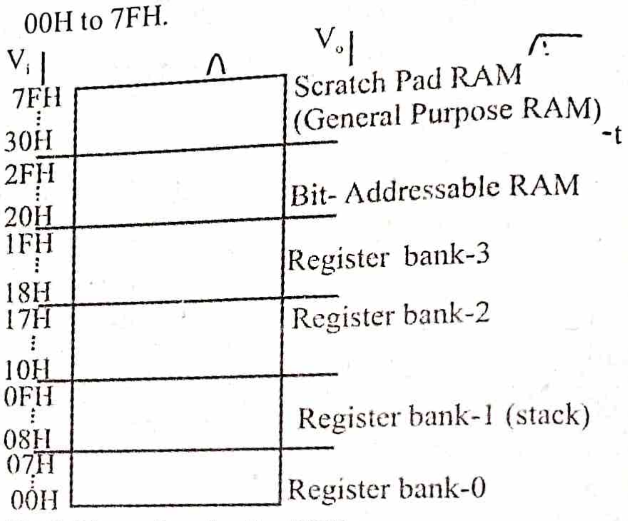

8051
P1.0 1
P1.1 2
P1.2 3
P1.3 4
P1.4 5
P1.5 6
P1.6 7
P1.7 8
RST 9
(RXD) P3.0 10
(TXD) P3.1 11
(INT0) P3.2 12
(INT1) P3.3 13
(T0) P3.4 14
(T1) P3.5 15
(WR) P3.6 16
(RD) P3.7 17
XTAL2 18
XTAL1 19
GND 20
40 Vcc
39 P0.0 (AD0)
38 P0.1 (AD1)
37 P0.2 (AD2)
36 P0.3 (AD3)
35 P0.4 (AD4)
34 P0.5 (AD5)
33 P0.6 (AD6)
32 P0.7 (AD7)
31 EA/VPP
30 ALE/PROG
29 PSEN
28 P2.7 (A15)
27 P2.6 (A14)
26 P2.5 (A13)
25 P2.4 (A12)
24 P2.3 (A11)
23 P2.2 (A10)
22 P2.1 (A9)
21 P2.0 (A8)

☞ Remember point

- ➢ It is 8 bit microcontroller
- ➢ Microcontroller also known as single chip microcomputer.
- ➢ It has 128 byte of internal RAM and 4K byte of on-chip (ROM)
- ➢ 16 bit address bus and 8-bit data bus
- ➢ 32 general purpose register each of 8-bit
- ➢ 16-bit timer (usually 2, but may have more or less)
- ➢ 40 pins IC package
- ➢ Single power supply of +5V
- ➢ It is available in N-MOS and C-MOS technology
- ➢ 8051 microcontroller design by Intel (1981)
- ➢ External RAM 64-kbyte
- ➢ External ROM is 64-kbyte
- ➢ Maximum clock frequency 12 MHz
- ➢ 8051 microcontroller has 8-bit PSW
- ➢ In 8051 microcontroller, PC & DPTR (Data Pointer) are 16-bit register
- ➢ 8051 microcontroller has 8-bit SP(Stack Pointer)
- ➢ 8051 microcontroller has one-serial port.
- ➢ PSW (Program Status Word) consist of 4-math Flags (AC,CY,P,OV) and two register bank select bits.
- ➢ 8051 microcontroller has 21 SFR (Special Function Register)

■ Internal RAM of 128-byte:

- ➢ The address range of 128-byte internal RAM is 00H to 7FH.


Vᵢ
Vₒ
7FH
30H
2FH
20H
1FH
18H
17H
10H
0FH
08H
07H
00H
Scratch Pad RAM (General Purpose RAM)
Bit- Addressable RAM
Register bank-3
Register bank-2
Register bank-1 (stack)
Register bank-0

(RAM Location in the 8051)

Pins 1-8	These pins are known as port 1. This port does not serves any other instructions. It is internally pulled up, bidirectional I/O port.
Pin 9	It is a RESET pin, which is used to reset the microcontroller to its initial values.
Pins 10-17	These pins are known as port 3. This port serves some function like interrupt timer input, control signal, serial communication signals RXD and TXD, etc.
Pins 18 -19	These pins are used for interfacing an external crystal to get the system clock.
Pin 20	This pin provides the ground to the circuit.
Pins 21-28	These pins are known as port 2. It serves as I/O port. Higher order address bus signal are also multiplexed
Pin 29	This is PSEN pin which stand for program store enable. It is used to read a signal from the external program memory.
Pin 30	This is a ALE Pin which stands for address latch enable. It is used to de-multiplex the address data signal of port.

Pin 31	This is a EA pin which stands for External Access input. It is used to enable/disable the external memory interface.
Pins 32-39	These pins are known as port 0, It serves as I/O Port, lower order address and data bus signals are multiplexed using this port.
Pin 40	This pins used to provide power supply to the circuit.

- **In 8051 there are six types of addressing mode.**

Addressing Mode	Examples
Immediate addressing mode	MOV A, # 0AFH. (Load 0AF into A)
Register addressing mode	MOV A, R5 (Copy the content of R5 into A)
Direct addressing mode	MOV R2, 45H (Copy the content of RAM location 45H in R2)
Register indirect addressing mode	MOV A, @ R0 (Move content of RAM location whose address is held by R0 into A
Indexed addressing mode	MOVC A, @ A + DPTR
Implied addressing mode	RLA

Interrupt Vector of 8051 :-

Interrupt	ROM location (in HEX)	Pin
Reset	0000	9
Internal Hardware interrupt (INTO)	0003	12
Timers 0 interrupt (TS0)	000B	13
External Hardware interrupt (ENT1)	0013	
Timer 1 interrupt (TF1)	001B	
Serial Communication	0023	

- **Features of 8051, 8052 and 8031**

Feature	8051	8052	8031
ROM (Bytes)	4 K	8 K	0 K
RAM (Bytes)	128	256	128
Timers	2	3	2
I/P Pins	32	32	32
Serial Port	1	1	1
Interrupt sources	6	8	6

- **Some important microcontroller ICs –**

Intel 8155	The 8155 includes 256 bytes of RD/WR memory i.e. RAM, 3 I/O ports and a 16-bit timer.
Intel 8257	(Programmable DMA Controller) Intel 8257 DMA Controller chip is a 40-pin programmable integrated Circuit. The DMA controller chip 8257 works in two modes, slave mode and master mode.
Intel 8259	(Programmable Interrupt controller) It is designed for the 8085 and Intel 8086 microprocessor. The 8259 combines multiple interrupt input source into a signal interrupt output to the host microprocessor.
Intel 8272	(Floppy Disk Controller) The function of floppy disk controller is to interface a floppy disk system to a microprocessor.
Intel 8275	(Programmable CRT Controller) an Intel 8275 is a single chip device. Its function is to interface CRT raster scan display with the microcomputer.
Intel 8279	(Programmable Keyboard/display interface) The INTEL 8279 is a keyboard/Display controller specially developed for interfacing keyboard and display device to Intel 8085,8086 and 8088 microprocessor.

- **Other microcontroller and its applications -**

Microcontroller	Name of company	Size	Application
TMS 1000	Texas Instrument	4-bit	Toys control and applications
TLCS 47	Toshiba	4-bit	
MSM 6411	OKI	4-bit	
COP 420	National	4-bit	
87C 552	Philips	8-bit	Instrumentation and simple industrial control
TMS 7500	Texas Instruments	8-bit	
PIC 16C 6X	Microchip	8-bit	
6500	Rockwell's	8-bit	

- **RS-232 Interface :** Communication defined by RS-232 is serial data communication. There is a single wire or link, for each direction of data flow, and the bits of the message are sent in sequence once at a time.

The RS-232 specification is intended to provide reliable communication up to a distance of soft, at rates up to 20,000 band. In RS-232 interface ASCII format is often used.

NETWORK THEORY

Units and Dimensions

Quantities	Unit	Dimension
Resistance	Ohm	$\left[ML^2T^{-3}A^{-2}\right]$
Resistivity	Ohm-meter	$\left[ML^3T^{-3}A^{-2}\right]$
Conductivity	mho/m or Siemens/m	$[M^{-1}L^{-3}T^3A^2]$
Voltage	Volt	$[ML^2T^{-3}A^{-1}]$
Current	Ampere	$[A]$
Electric Power	Watt	$[ML^2T^{-3}]$
Electric Energy	kWh	$[ML^2T^{-2}]$
Permittivity	Farad/meter	$[M^{-1}L^{-3}T^4A^2]$
Electric field intensity	V/m or N/C	$[MLT^{-3}A^{-1}]$
Capacitance	Farad	$[M^{-1}L^{-2}T^4A^2]$
Inductance	Henry	$[ML^2T^{-2}A^{-2}]$
Permeability	Henry/meter	$[MLT^{-2}A^{-2}]$
Magnetic field Density	Wb/m^2	$[MT^{-2}A^{-1}]$
mmf	AT or Gilbert	$[A]$
Reluctance	AT/Wb or per Henry	$[M^{-1}L^{-2}T^2A^2]$
Permeance	Wb/AT	$[ML^2T^{-2}A^{-2}]$
Luminous flux	lumen	$[ML^2T^{-3}]$
Illumination	Lux or lumen/ m^2	$[MT^{-3}]$

Resistor

Resistance (R) = $\frac{\rho\ell}{A}$

If wire is stretched n times then- $\boxed{R' = n^2R}$

If wire is compressed n times then- $\boxed{R' = \frac{R}{n^2}}$

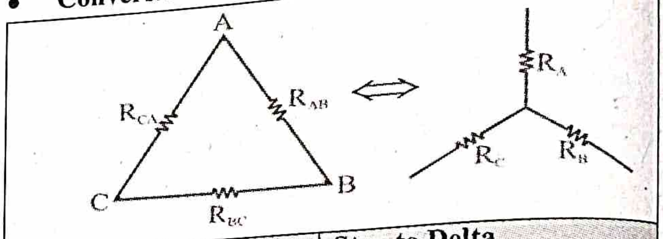
- **Ohm's Law**

Condition	constant temperature and pressure.
Formula	$\frac{V}{I} = R$
Non-applicable	Non metallic conductor, non-linear devices.

- **Characteristic of Resistor**

Series connection	Same current flows through all parts of the circuit. Different resistors have their individual voltage drops. Voltage drops are additive. Applied voltage equals the sum of different voltage drops. Resistance are additive. Power are additive. $R_{eq} = R_1+R_2+R_3+........+R_n$
Parallel connection	Same voltage acts across all parts of the circuit. Different resistors have their individual current. Branch current are additive. Power are additive. $\frac{1}{R_{eq}} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + ... + \frac{1}{R_n}$
Types of resistor	Carbon composition resistor Deposited carbon resistor High voltage ink film resistor Metal film resistor Metal glaze resistor Wire wound resistor Ceramic metal resistor

- **Conversion of Resistance–**

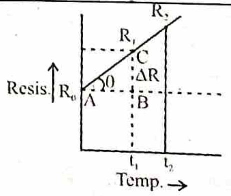


Delta to Star	**Star to Delta**
$R_A = \frac{R_{AB} \times R_{CA}}{R_{AB} + R_{BC} + R_{CA}}$	$R_{AB} = R_A + R_B + \frac{R_AR_B}{R_C}$
$R_B = \frac{R_{AB} \times R_{BC}}{R_{AB} + R_{BC} + R_{CA}}$	$R_{BC} = R_B + R_C + \frac{R_BR_C}{R_A}$
$R_C = \frac{R_{BC} \times R_{CA}}{R_{AB} + R_{BC} + R_{CA}}$	$R_{CA} = R_C + R_A + \frac{R_CR_A}{R_B}$

For same value of resistance-

$$\boxed{R_\Delta = 3R_y}$$

- **Effect of Temperature on Resistance**

Effect	When the temperature increases then resistance also increases. For metal temperature coefficient of resistance (α) is positive. For semiconductor and insulator temperature coefficient of resistance (α) is negative.
Formula	 $\alpha_0 = \frac{\text{Slope of Graph}}{\text{Original Resistance}}$, $\alpha_1 = \frac{\text{Slope of Graph}}{R_1}$ $\alpha_0R_0 = \alpha_1R_1$ $\alpha_1 = \frac{\alpha_0}{1+\alpha_1t_1}$ $R_1 = R_0[1+\alpha_0t_1]$

- **AC Resistance** $\boxed{R_{AC} = 1.6\, R_{DC}}$
- **Resistivity of materials-**

$$\boxed{\rho = \frac{1}{\sigma(\text{conductivity})}\ \Omega\text{-m}}$$

- **Cable insulation Resistance-**

$$\boxed{R = \frac{\rho}{2\pi\ell}\log_e\frac{r_2}{r_1} = \frac{2.303\rho}{2\pi\ell}\log_{10}\frac{r_2}{r_1}}$$

- **Colour Coding of Resistance**

Colour	Value	Multiplier	Tolerance
Black	0	1	–
Brown	1	10	± 1%
Red	2	10^2	± 2%
Orange	3	10^3	± 3%
Yellow	4	10^4	± 4%
Green	5	10^5	± 0.5%
Blue	6	10^6	± 0.25%
Violet	7	10^7	± 0.10%
Grey	8	10^8	± 0.05 %
White	9	10^9	–
Gold	–	10^{-1}	± 5%
Silver	–	10^{-2}	± 10%
(None)	–		± 20%

- **Formula for 4 Band Resistor**

$R = AB \times 10^C \pm \text{Tolerance}$
Where A → I^{st} significant digit
B → 2^{nd} Significant digit
10^C → multiplier

- **Metal and Melting Point (in ^{0}C)**

Metal	Melting point (in °C)	Metal	Melting point (in °C)
Copper	1084	**Chromium**	1907
Magnesium	650	**Molybdenum**	2622
Zinc	419.5	**Tungsten**	3410
Aluminium	658.6	**Iron**	1538
Tin	231.8	**Cobalt**	1490
Lead	327.4	**Nickel**	1452
Silver	961	**Carbon**	3550

- **Behaviour of Resistor**

Resistor is a linear, bilateral and passive element.

- **Material and Dielectric Constant**

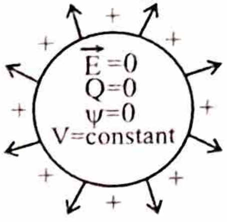
Material	Dielectric Constant	Material	Dielectric Constant
Vacuum	1	**Paper**	1.8-2.6
Glass	5-12	**Polystyrene**	2.6
Mica	4-8	**Air (100 atm)**	1.0548
Germanium	16	**Porcelain**	5-6.2
Water	80.6	**Rubber**	2.5
Air (1 atm)	1.00059	**Bakelite**	5

- **Properties of Electric Lines of Forces**

(i) Electric lines never intersect each other.
(ii) Electric lines leave or enter the charged surface normally
(iii) Electric lines cannot pass through a conductor. It means that electric field inside a conductor is zero(0)

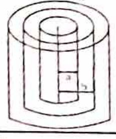
- **Behavior of Metallic Conductors in Electric Field**

(i) No electric field exist inside the conductor.
(ii) No electric lines exist inside the conductor.
(iii) Net charge inside a charged conductor is zero
(iv) The electric field on the surface of a charge conductor is perpendicular to the surface of the conductor at every point
(v) The magnitude of electric field just outside a charge conductor is σ/ε_0
where, σ = surface charge density.
(vi) The electric potential is the same (i.e. constant) at the surface and inside the charge the conductor.



$$\vec{E} = \frac{\sigma}{\varepsilon_0}$$

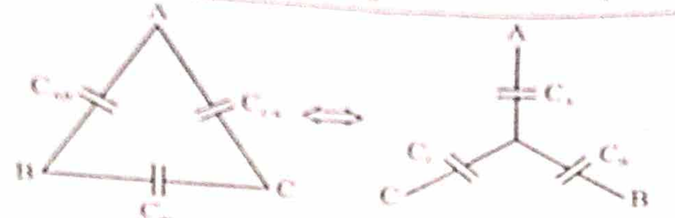
☐ **Capacitor**

Capacitance of Capacitor	$C = \frac{\varepsilon_0\varepsilon_r A}{d}$ Farad
Capacitance of different Dielectric having different thickness and relative permittivities	$C = \frac{\varepsilon_0 A}{\frac{t_1}{\varepsilon_{r_1}} + \frac{t_2}{\varepsilon_{r_2}} + \frac{t_3}{\varepsilon_{r_3}}}$ Farad
When some part of parallel plate capacitor have air medium and some part have another medium then capacitance	$C = \frac{\varepsilon_0 A}{\left[d - \left(t - \frac{t}{\varepsilon_r}\right)\right]}$ Farad
When some part of parallel plate capacitor have air medium in horizontal direction and some part have another medium then capacitance	$C = \frac{\varepsilon_0 A}{d}\left[\frac{1+\varepsilon_r}{2}\right]$ $= C_{air}\left[\frac{1+\varepsilon_r}{2}\right]$ Farad
Capacitance of cylindrical capacitor 	$C = \frac{2\pi\varepsilon_0\varepsilon_r\ell}{\log_e b/a}$ Farad $C = \frac{2\pi\varepsilon_0\varepsilon_r\ell}{2.303\log_{10} b/a}$ Farad
Capacitance of variable capacitor	$C = \frac{(n-1)\varepsilon_0\varepsilon_r A}{d}$ Farad Where n = no. of plates

- **Combination of Capacitors**

Series	$\frac{1}{C_{eq}} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3} + \ldots\ldots\ldots + \frac{1}{C_n}$
Parallel	$C_{eq} = C_1 + C_2 + C_3 + \ldots\ldots + C_n$

- **Conversion of Capacitors–**



Delta to Star	**Star to Delta**
$C_A = C_{AB} + C_{CA} + \frac{C_{AB}\,C_{CA}}{C_{BC}}$	$C_{AB} = \frac{C_A\,C_B}{C_A + C_B + C_C}$
$C_B = C_{AC} + C_{BC} + \frac{C_{AC}\,C_{BC}}{C_{AB}}$	$C_{BC} = \frac{C_B\,C_C}{C_A + C_B + C_C}$
$C_C = C_{BC} + C_{AB} + \frac{C_{BC}\,C_{AB}}{C_{AC}}$	$C_{CA} = \frac{C_C\,C_A}{C_A + C_B + C_C}$
For same value of capacitance- $\boxed{C_x = \frac{1}{3}C_y}$	

- **Charging and Discharging of Capacitor**

Charging	**Discharging**	**Time constant for capacitor**
Current equation $I_c(t) = I_0 e^{-t/\tau}$	Current equation $I_c(t) = -I_0 e^{-t/\tau}$	$\tau = R_{th} C_{eq}$
Voltage equation $V_c(t) = V_0\left(1 - e^{-t/\tau}\right)$	Voltage equation $V_c(t) = V_0 e^{-t/\tau}$	
Charge equation $q_c(t) = Q_0\left(1 - e^{-t/\tau}\right)$	Charge equation $q_{c(t)} = Q_0 e^{-t/\tau}$	

- **Transient Equation for Capacitor–**

$$\boxed{V_c(t) = V_c(\infty) + \left[V_c(0^+) - V_c(\infty)\right]e^{-t/\tau}\,t > 0}$$

- **Concept of short circuit and open circuit of capacitor with respect to time-**

$$i_c = \frac{CdV}{dt}; \qquad V_c(t) = \frac{1}{C}\int_0^t i_c(t)\,dt + V(0^-)$$

- **Behaviour of Capacitor -**

With initial condition	at $t = 0^+$ → act as a voltage source at $t = \infty$ → act as open circuit
without initial condition	at $t = 0$ → act as short circuit at $t = \infty$ → act as open circuit

- **Some important point Regarding to Capacitor–**

a. Capacitor opposes rate of change of voltage.
$V_C(0^-) = V_C(0^+)$

b. Capacitor Stores the energy in electric field.

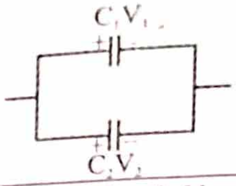
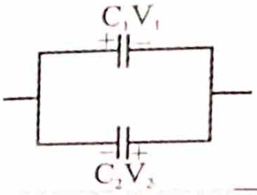
c. While charging, $I_c(t) = \frac{CdV_c(t)}{dt}$ decreased and $I_C(t)$ must be positive.

d. While discharge, $I_c(t) = \frac{CdV_c(t)}{dt}$ decreased b
$I_c(t)$ must be negative.

e. While a capacitor charge and discharge polarity o dc voltage of capacitor never change.

- **Energy Stored in Capacitor –**

$$\boxed{E = \frac{1}{2}CV^2 = \frac{1}{2}QV = \frac{1}{2}\frac{Q^2}{C}} \text{ Joules}$$

Common potential (for parallel)	$V = \frac{C_1V_1 + C_2V_2}{C_1 + C_2}$ 
Connection of two capacitor parallel/anti-parallel	$V = \frac{C_1V_1 - C_2V_2}{C_1 + C_2}$ 

- **Energy Lost in Joining Capacitor**

For parallel	$\Delta E = \frac{1}{2}\frac{C_1C_2}{(C_1 + C_2)}(V_1 - V_2)^2$
For anti-parallel	$\Delta E = \frac{1}{2}\frac{C_1C_2}{(C_1 + C_2)}(V_1 + V_2)^2$

❑ Inductor

- **Faraday's law for an inductor**

$$\boxed{V_L = L\frac{di}{dt}} \qquad \boxed{i(t) = \frac{1}{L}\int_0^t V_L\,dt + i(0^-)}$$

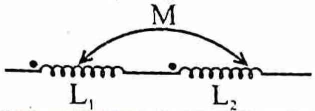
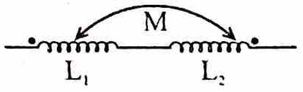
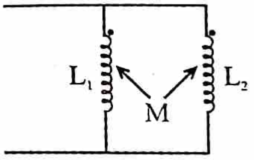
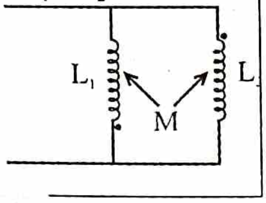
- **Types of inductance**

Self inductance	$\boxed{L = \frac{N\phi}{i} = \frac{V_L}{di/dt} = \frac{N^2}{S} = \frac{\mu_0\mu_r aN^2}{\ell}}$ Where N = no. of turns in the coil, 'a' is cross sectional area and ℓ is the length of the coil. Also, μ_r = Relative permeability $\mu_0 = 4\pi \times 10^{-7}$ Henry/meter S = Reluctance
Mutual Inductance	$\boxed{M = \frac{N_2\phi_1}{i_1} = \frac{V_{L_2}}{di_1/dt} = \frac{\mu_0\mu_r N_1N_2\pi r^2}{\ell_1}}$ $\boxed{M = \frac{\mu_0\mu_r N_1N_2A}{\ell_1}}$
Coupling factor of Inductance	$\boxed{K = \frac{M}{\sqrt{L_1L_2}}}$

- **Behaviour of Inductor**

Inductor with initial condition	at $t = 0^+ \rightarrow$ act as a current source at $t = \infty \rightarrow$ act as short circuit
Inductor without initial condition	at $t = 0 \rightarrow$ act as an open circuit at $t = \infty \rightarrow$ act as short circuit

- **Energy stored in inductor-** $\boxed{E = \frac{1}{2}Li^2}$
- **Magnetic Coupling of Inductor**

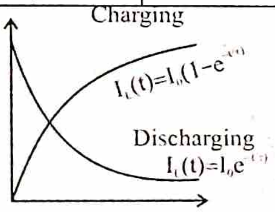
Series Connection of Inductor	
i. Aiding nature $L = L_1 + L_2 + 2M$ 	**ii. Opposing nature** $L = L_1 + L_2 - 2M$ 
Parallel Connection of Inductor	
i. Aiding nature $L_{eq} = \frac{L_1L_2 - M^2}{L_1 + L_2 - 2M}$ 	**ii. Opposing nature** $L_{eq} = \frac{L_1L_2 - M^2}{L_1 + L_2 + 2M}$ 

- **Transient Equation for Inductor**

$$\boxed{i_L(t) = i_L(\infty) + \left[i_L(0^+) - i_L(\infty)\right]e^{-t/\tau} \quad t > 0}$$

- **Charging and Discharging of Inductor**

Charging	**Discharging**
Current $I_L(t) = I_o\left(1 - e^{-t/\tau}\right)$	Current $I_L(t) = I_oe^{-t/\tau}$
Voltage $V_L(t) = V_oe^{-t/\tau}$	Voltage $V_L(t) = -V_oe^{-t/\tau}$



- **Time constant for inductor** $\tau = \frac{L}{R}$ second

- **Behaviour of Inductor**

a. Inductor is linear, bilateral and passive element.
b. Inductor opposes the sudden change of current.
$I_L(0^-) = I_L(0^+)$
c. Inductor allows the sudden change of voltage.
d. Inductor is an energy storing element.
e. Inductor does not dissipate any power, it only stores energy.

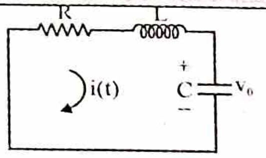
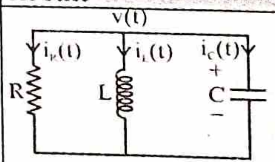
- **Analysis of Coupled Circuits**
- **Similarities**

Electric Circuit	**Magnetic Circuit**
The closed path for electric current is called an electric circuit.	The closed path for magnetic flux is called a magnetic circuit.
Exciting force = Voltage/EMF [Units : Volts]	MMF → Magnetic motive force → MMF = N.I Units: Ampere-turns (AT)
Response = 'Current' (I) [units: Ampere (A)]	Response = 'Flux' [units : webers (Wb)]
Ohms Law: $R = \frac{V}{I}$, where, R = Resistance; [unit : Ω]	Ohms Law: $S = \frac{MMF}{\phi} = \frac{Ni}{\phi}$, where, S = Reluctance, $\left[\text{unit} = \frac{AT}{Wb}\right]$
In electrical material $R = \frac{\rho\ell}{a}$	In magnetic material $S = \frac{\ell}{\mu a}$
Electric field intensity: $E = \frac{V}{d}$ [unit: volt/m]	Magnetic Field intensity: $H = \frac{MMF}{\ell} = \frac{N.i}{\ell}; \left[\text{Unit}: \frac{AT}{m}\right]$
Electric Current Density: $J = \frac{I}{a}; \left[\text{Unit}: \frac{A}{m^2}\right]$	Magnetic Flux Density $B = \frac{\phi}{a}; \left[\text{unit}: \frac{Wb}{m^2} (\text{or}) \text{Tesla}(T)\right]$
$J = \sigma E$ (J = Electric current density) (σ = Conductivity)	$B = \mu H$ (B = Magnetic flux density) $\mu = \mu_0\mu_r$
In series, $R_s = R_1 + R_2$, In parallel, $\frac{1}{R_p} = \frac{1}{R_1} + \frac{1}{R_2}$	In series, $S_s = S_1 + S_2$, In parallel, $\frac{1}{S_P} = \frac{1}{S_1} + \frac{1}{S_2}$

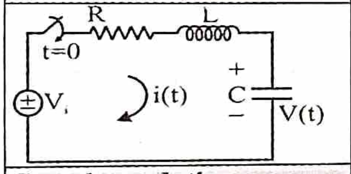
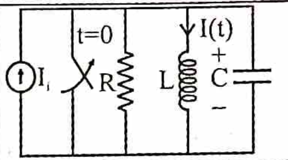
- **Dissimilarities**

Magnetic flux does not flow.	The electric current actually flows in an electric circuit.
There is no magnetic insulator. For example, flux can be set up even in air (the best known magnetic insulator) with reasonable m.m.f.	There are a number of electric insulators. For instance, air is a very good insulator and current can not pass through it.

- **Transient Equation for RLC circuit -**

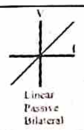
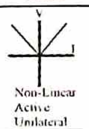
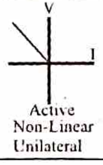
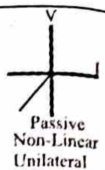
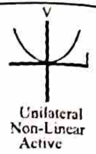
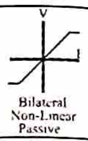
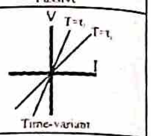
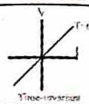
Source free series RLC circuit	**Source free parallel RLC circuit**
	
roots $s_1, s_2 = -\alpha \pm \sqrt{\alpha^2 - \omega_o^2}$ Damping coefficient $\boxed{\alpha = \frac{R}{2L}}$	roots $s_1, s_2 = -\alpha \pm \sqrt{\alpha^2 - \omega_o^2}$ Damping coefficient $\boxed{\alpha = \frac{1}{2RC}}$

Overdamped	**Overdamped**
• $\alpha > \omega_o \Rightarrow C > 4L/R^2$ • $i(t) = A_1e^{s_1t} + A_2e^{s_2t}$ • $\xi > 1$	• $\alpha > \omega_o \Rightarrow L > 4R^2C$ • $v(t) = A_1e^{s_1t} + A_2e^{s_2t}$ • $\xi > 1$
Critically damped	**Critically damped**
• $\alpha = \omega_o \Rightarrow C = 4L/R^2$ • $i(t) = (A_1 + A_2t)e^{-\alpha t}$ • $\xi = 1$	• $\alpha = \omega_o \Rightarrow L = 4R^2C$ • $v(t) = (A_1 + A_2t)e^{-\alpha t}$ • $\xi = 1$
Under damped	**Under damped**
• $\alpha < \omega_o \Rightarrow C < 4L/R^2$ • $s_1,s_2 = -\alpha \pm j\omega_d$ Where $\omega_d = \sqrt{\omega_o^2 - \alpha^2}$ • $i(t) = e^{-\alpha t}(A_1\cos\omega_d t + A_2 \sin \omega_d t)$ • Time constant $= \frac{1}{\alpha} = \frac{2L}{R}$ • Period $(T) = \frac{2\pi}{\omega_o}$ • $\xi < 1, \quad \xi = \frac{R}{2}\sqrt{\frac{C}{L}}$	• $\alpha < \omega_o \Rightarrow L < 4R^2C$ • $s_1,s_2 = -\alpha \pm j\omega_d$ Where $\omega_d = \sqrt{\omega_o^2 - \alpha^2}$ • $v(t) = e^{-\alpha t}(A_1\cos\omega_d t + A_2 \sin \omega_d t)$ • Time constant$= \frac{1}{\alpha} = 2RC$ • Period $(T) = \frac{2\pi}{\omega_o}$ • $\xi < 1, \quad \xi = \frac{1}{2R}\sqrt{\frac{L}{C}}$
Note : The constant A_1 & A_2 can be determined from initial condition $i(0^+)$ & $di(0^+)/dt$ and $v(0^+)$ & $dv(0^+)/dt$	

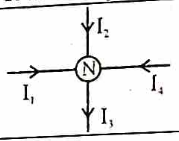
Step response of series RLC circuit	**Step response of parallel RLC circuit**
 R L t=0 V_i i(t) + C − V(t)	
Complete solution	**Complete solution**
• Over damped - $V(t) = V_i + A_1e^{s_1t} + A_2e^{s_2t}$ • Critically damped $V(t) = V_i + (A_1 + A_2t)\,e^{-\alpha t}$ • Under damped - $V(t) = V_i + e^{-\alpha t}(A_1 \cos\omega_d t + A_2\sin\omega_d t)$	• Over damped - $I(t) = I_i + A_1e^{s_1t} + A_2e^{s_2t}$ • Critically damped $I(t) = I_i + (A_1 + A_2t)\,e^{-\alpha t}$ • Under damped - $I(t) = I_i + e^{-\alpha t}(A_1 \cos\omega_d t + A_2\sin\omega_d t)$

☐ Electric Circuit

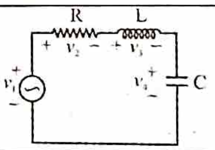
- **Classification of circuit element**

Linear Element	whose parameters are constant with time and they do not change with voltage or current	 V I Linear Passive Bilateral
Non-Linear Element	whose parameters change with voltage or current	 V I Non-Linear Active Unilateral
Active Element	Capable of delivering the energy for infinite time **Ex.** Current source op-amp, BJT etc.	 V I Active Non-Linear Unilateral
Passive Element	Not capable of delivering energy for infinite time. **Ex.** R,L,C, Bulb, Transformer etc.	 V I Passive Non-Linear Unilateral
Unilateral Element	It allows the flow of current in one direction only **Ex.** Diode, SCR etc.	 V I Unilateral Non-Linear Active
Bilateral Element	It allows the flow of the current in both direction **Ex.** R, L, C	 V I Bilateral Non-Linear Passive
Time variant Element	If the response of the system to an Input is a function of time	 V T=t T=t I Time-variant
Time Invariant Element	If the response to an input is not alter with time	 V I Time-invariant

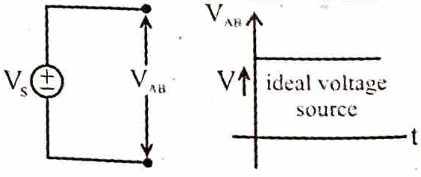
☐ Kirchhoff's Current Law

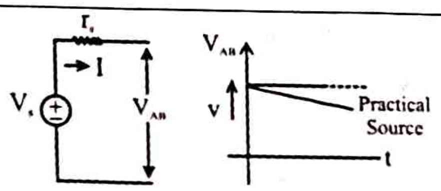
Principle	Law of conservation of charge. It is always defined at a node.
Figure	
Formula	Outgoing current = incoming current. $\sum \pm I = 0$ $\boxed{I_3 = I_1 + I_2 + I_4}$ $\boxed{q_3 - (q_1 + q_2 + q_4) = 0}$

☐ Kirchhoff's Voltage Law (KVL)

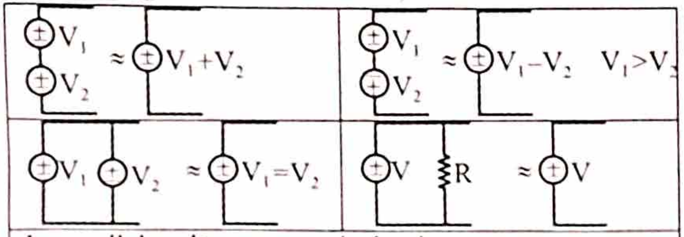
Principle	Law of conservation of energy. It is always defined in a loop are mesh i.e., in a closed circuit.
Figure	 R L + v_2 − + v_3 − v_1 v_4 C
Formula	$\sum V = 0$ $\boxed{-v_1 + v_2 + v_3 + v_4 = 0}$

- **Voltage source**

Ideal voltage source	 V_S V_AB V_AB V ideal voltage source t r = 0, where r is internal resistance $V_{AB} = V_S$ **Note:** Internal resistance of ideal voltage source is zero.

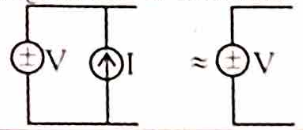
Practical voltage source	 r_s I V_s V_{AB} v Practical Source t $r_s \neq 0 \quad V_{AB} = V_s - Ir_s$ **Note:** The internal resistance of practical voltage source is not zero

- **Voltage Source Connection**

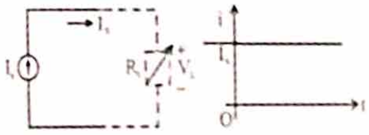
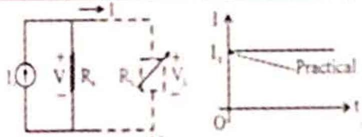


V_1
V_2
≈ V_1+V_2
V_1
V_2
≈ V_1-V_2 $V_1>V_2$
V_1 V_2 ≈ $V_1=V_2$
V R ≈ V

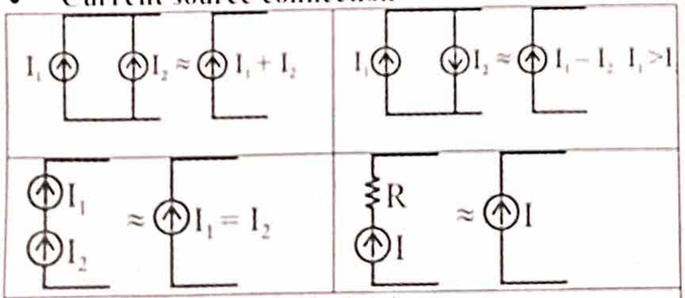
In parallel, voltage source is dominant.



❑ Current Source

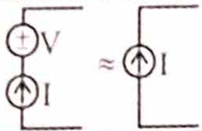
Ideal Current Source	 I_s I_s R_L V_L i I_s 0 t $I = I_s \quad R_s = \infty$ **Note:** The internal resistance of an ideal current source is infinite
Practical Current Source	 I I_s V R_s R_L V_L I I_s Practical 0 t $I = I_s - \frac{V}{R_s}$ **Note:** The internal resistance of practical current source is not infinite.

- Current source connection



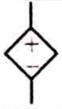
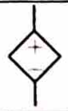
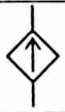
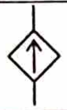
I_1 I_2 ≈ I_1+I_2
I_1 I_2 ≈ I_1-I_2 $I_1>I_2$
I_1
I_2
≈ $I_1=I_2$
R
I
≈ I

In series, current source is dominant.

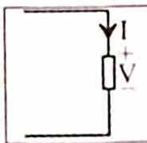
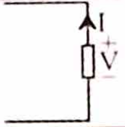


Source	Ideal	Practical
Voltage Source	$R_s = 0$	R_s = Low
Current Source	$R_s = \infty$	R_s = High
Voltmeter	$R_m = \infty$	R_m = High
Ammeter	$R_m = 0$	R_m = Low

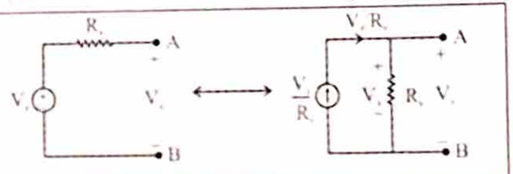
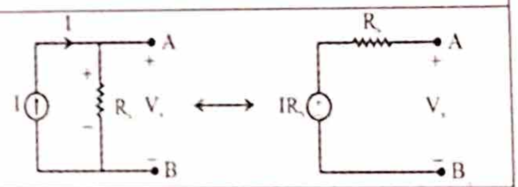
❑ Dependent source

Source	Parameter to control
 $V(t)= ki$	Current controlled voltage source
 $V(t)= kv$	Voltage controlled voltage source
 $I(t)= kv$	Voltage controlled current source
 $I(t)= ki$	Current controlled current source

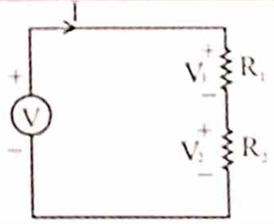
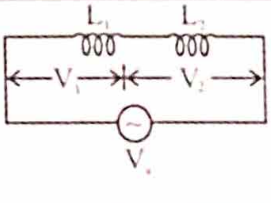
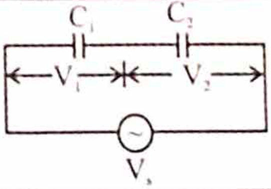
❑ Power absorbed and delivered by element

	When current is entering into positive terminal, element absorbs power.
	When current is leaving from positive terminal, element delivers power.

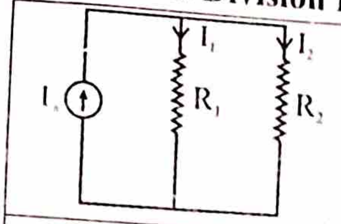
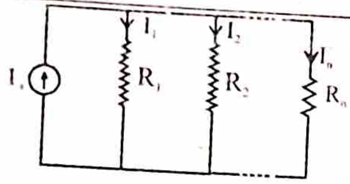
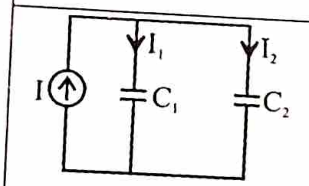
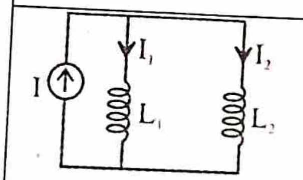
❑ Source Transformation Technique

Voltage source to current source conversion	 R_s A V_s V_s B V_sR_s A $\frac{V_s}{R_s}$ V_s R_s V_s B
Current source to voltage source conversion	 I A I R_s V_s B R_s A IR_s V_s B

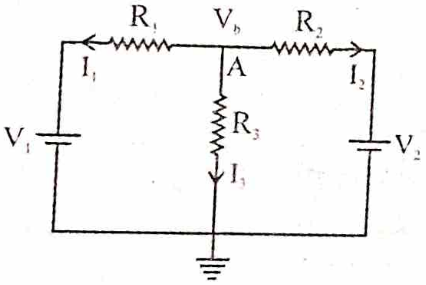
- **Voltage Division Rule**

 I V V_1 R_1 V_2 R_2	$V_1 = \frac{R_1}{R_1+R_2} \times V$ $V_2 = \frac{R_2}{R_1+R_2} \times V$
 L_1 L_2 V_1 V_2 V_s	$V_1 = V_s\frac{L_1}{L_1+L_2}, V_2 = V_s\frac{L_2}{L_1+L_2}$
 C_1 C_2 V_1 V_2 V_s	$V_1 = V_s\frac{C_2}{C_1+C_2}, V_2 = V_s\frac{C_1}{C_1+C_2}$

Current Division Rule

	$I_1 = \frac{R_2}{R_1+R_2}\times I_s$ $I_2 = \frac{R_1}{R_1+R_2}\times I_s$
	$I_k = \frac{I_s \times \frac{1}{R_k}}{\frac{1}{R_1}+\frac{1}{R_2}+\dots\frac{1}{R_n}}$
	$I_1 = \frac{IC_1}{C_1+C_2}$ $I_2 = \frac{IC_2}{C_1+C_2}$
	$I_1 = \frac{IL_2}{L_1+L_2}$ $I_2 = \frac{IL_1}{L_1+L_2}$

Nodal Voltage Analysis circuit :

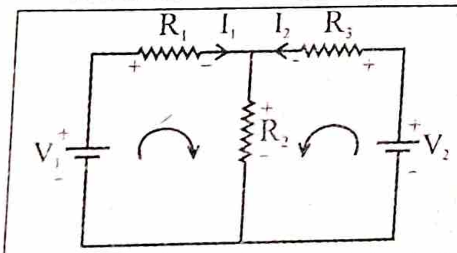


- At node A-

$$\frac{V_b - V_1}{R_1} + \frac{V_b - V_2}{R_2} + \frac{V_b}{R_3} = 0\,, \quad I_1 + I_2 + I_3 = 0$$

- Nodal analysis is an application of Kirchhoff's current law.
- Nodal → KCL + Ohm's law
- Super node→ KVL + KCL + Ohm's law
- Number of equation in nodal analysis = N-1
  N = Number of nodes

Mesh Current Analysis Circuit



$$V_1 - I_1R_1 - (I_1 + I_2)R_2 = 0\,,\ V_2 - I_2R_3 - (I_1 + I_2)R_2 = 0$$

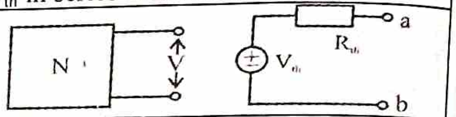
- Mesh analysis is used only for planer network.
- Number of equations in mesh analysis = B–(N–1)
- Mesh→ KVL+ ohm's law
- Supermesh→ KVL+KCL+ ohm's law

☐ Network Theorems

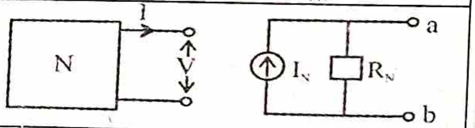
☐ Superposition Theorem-

Principle	The voltage across (or current through) an element in a linear circuit is the algebraic sum of the voltages across (or currents through) that element due to each independent source acting alone.
Applicable	It is applicable Linear and bilateral network. It follows the condition of homogeneity.
Use	It is used for voltage and current calculation. It is not used for power calculation.

Thevenin's Theorem

Principle	It states that a linear two-terminal circuit can be replaced by an equivalent circuit consisting of a voltage source V_{th} in series with a resistor R_{th},
Circuit	
Applicable	Linear network that is network with R,L,C transformer and linear control sources of element Both active as well as passive network
Use	It is used for calculation of electronic circuit. It is also used vacuum tube circuit

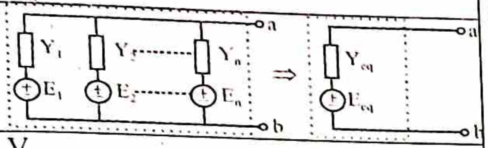
☐ Norton's Theorem -

Principle	It states that a linear two terminal circuit can be replaced by an equivalent circuit consisting of a current source I_N in parallel with a resistor R_N,
Circuit	
Applicable	Linear bilateral and active RLC network.
Use	For circuit analysis simplification and to study circuit's initial condition and steady-state response.

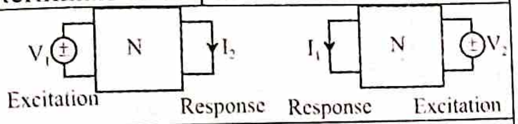
☐ Tellegen's Theorem-

Principle	States that the summation of instantaneous power delivered is zero for each branch of any electrical network at any instant of time.
Formula	$\sum_{k=1}^{b} P_k = v_k i_k = 0$ b= number of branches
Valid	Linear, non-linear, active, passive, time variant and time invariant circuit.
Use	Used to examine difficult network systems like electrical circuits, metabolic and biological networks, chemical processes and pipeline transport networks.

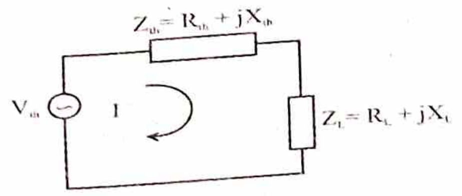
☐ Millman's Theorem-

Principle	It states that if there are "n" number of voltage sources having magnitude E_1, E_2, E_3 ..... E_n having internal impedance Z_1, Z_2........Z_n respectively then these sources may be replaced by a single voltage source V_m having equivalent series internal impedance Z_m
Figure	 Y_1 Y_2 Y_n E_1 E_2 E_n a b ⇒ Y_{eq} E_{eq} a b
Equation	$V_m = \dfrac{V_1Y_1 + V_2Y_2 + V_3Y_3 + ... + V_nY_n}{Y_1 + Y_2 + ... + Y_n}$ $Z_m = \dfrac{1}{Y_1 + Y_2 + Y_3 + ... + Y_n}$
Used	It is used to compute the voltage at the ends of a circuit made up of only branches in parallel.

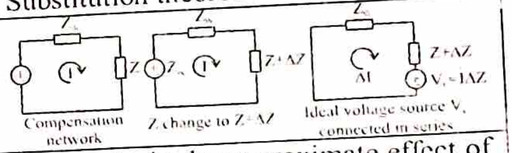
☐ Reciprocity Theorem-

Principle	In a linear, passive and bilateral network, the ratio of response to excitation is constant even though the source is interchanged from input terminals to output terminals.
Figure	 V_1 N I_2 I_1 N V_2 Excitation Response Response Excitation
Equation	$\dfrac{V_1}{I_2} = \dfrac{V_2}{I_1}$; $Z_{12} = Z_{21}$
Use	Reciprocity Theorem Used ● Linear Element ● Bilateral Element ● Passive Elements Not Used ● Dependent Source

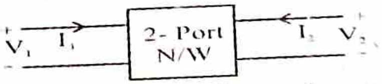
☐ Maximum Power Transfer Theorem-

Properties	For linear network i.e. network with R,L,C. It is also used for both active as well as passive network.
Applicable	Only when load is variable otherwise (i.e. load is fixed) choose the minimum internal impedance of the source.
Circuit	 $Z_{th} = R_{th} + jX_{th}$ V_{th} I $Z_L = R_L + jX_L$
Condition for maximum power transfer	• **Only R_L is variable & X_L fixed.** $\boxed{R_L = \sqrt{R_{th}^2 + (X_L + X_{th})^2}}$ • **Only X_L is variable & R_L fixed.** $\boxed{X_L = -X_{th}}$ • **If both are variable.** $\lvert Z_L \rvert = \lvert Z_{th} \rvert^*$ • **If load is purely Resistive** $R_L = \sqrt{R_{th}^2 + X_{th}^2}$
Application	MPT theorem is applied in Radio communications.

☐ Compensation Theorem-

Principle	If impedance 'Z' of any branch of an network is changed by ΔZ then the incremental current. ΔI in such branch is that which will be produced by a compensating voltage source $V_C = I\Delta Z$ the original direction of current I
Other name	Substitution theorem
Figure	 Z_s I Z Z_s I Z+ΔZ Z_s ΔI Z+ΔZ V_c = IΔZ Compensation network Z change to Z+ΔZ Ideal voltage source V_c connected in series
Application	Use to obtain the approximate effect of small changes in the elements of an electrical network.

☐ Two Port Network



➤ Maximum number of possible parameters for analysis of two port network is given by $N_o = {}^4C_2$

- **Parameters of two port network**

• **Z-Parameter (Impedance Parameter)** $V_1 = I_1Z_{11} + I_2Z_{12}$; $V_2 = I_1Z_{21} + I_2Z_{22}$; $\begin{bmatrix} V_1 \\ V_2 \end{bmatrix} = \begin{bmatrix} Z_{11} & Z_{12} \\ Z_{21} & Z_{22} \end{bmatrix}_{2\times2} \begin{bmatrix} I_1 \\ I_2 \end{bmatrix}_{2\times1}$ $\because I_1, I_2 \rightarrow$ Independent Variable $V_1, V_2 \rightarrow$ Dependent Variable
• **Y – Parameters (Admittance Parameter)** $I_1 = Y_{11}V_1 + Y_{12}V_2$; $I_2 = Y_{21}V_1 + Y_{22}V_2$; $\begin{bmatrix} I_1 \\ I_2 \end{bmatrix} = \begin{bmatrix} Y_{11} & Y_{12} \\ Y_{21} & Y_{22} \end{bmatrix}_{2\times2} \begin{bmatrix} V_1 \\ V_2 \end{bmatrix}_{2\times1}$ $\because V_1, V_2 \rightarrow$ Independent Variable $I_1, I_2 \rightarrow$ Dependent Variable
• **h–Parameter (hybrid Parameter)** $V_1 = I_1h_{11} + V_2h_{12}$; $I_2 = I_1h_{21} + V_2h_{22}$; $\begin{bmatrix} V_1 \\ I_2 \end{bmatrix} = \begin{bmatrix} h_{11} & h_{12} \\ h_{21} & h_{22} \end{bmatrix}_{2\times2} \begin{bmatrix} I_1 \\ V_2 \end{bmatrix}_{2\times1}$ $\because V_1, I_2 \rightarrow$ Dependent Variable $I_1, V_2 \rightarrow$ Independent Variable

- **g- Parameter (Inverse hybrid Parameter)**

$$I_1 = g_{11}V_1 + g_{12}I_2 \;;\; \begin{bmatrix} I_1 \\ V_2 \end{bmatrix} = \begin{bmatrix} g_{11} & g_{12} \\ g_{21} & g_{22} \end{bmatrix}_{2\times 2} \begin{bmatrix} V_1 \\ I_2 \end{bmatrix}_{2\times 1}$$
$$V_2 = g_{21}V_1 + g_{22}I_2$$

$\because$ I_1, V_2 → Dependent Variable

V_1, I_2 → Independent Variable

- **ABCD- Parameter (Transmission Parameter)**

$$V_1 = AV_2 - BI_2 \;;\; \begin{bmatrix} V_1 \\ I_1 \end{bmatrix} = \begin{bmatrix} A & B \\ C & D \end{bmatrix} \begin{bmatrix} V_2 \\ -I_2 \end{bmatrix}$$
$$I_1 = CV_2 - DI_2$$

$\because$ V_2, I_2 = Independent variable

V_1, I_1 = Dependent variable

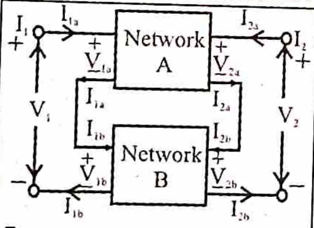
- z-parameters get added up in series connection.
- y-parameters get added up in parallel connection.
- h-parameter get added up in series parallel connection.
- g-parameter get added up in parallel series connection.
- ABCD- parameters are multiplied.

❑ Condition for network to be symmetrical & reciprocal.

Reciprocal	Symmetrical
$Z_{12} = Z_{21}$	$Z_{11} = Z_{22}$
$Y_{12} = Y_{21}$	$Y_{11} = Y_{22}$
$\begin{vmatrix} A & B \\ C & D \end{vmatrix} = 1$	A=D
$h_{12} = -h_{21}$	$\begin{vmatrix} h_{11} & h_{12} \\ h_{21} & h_{22} \end{vmatrix} = 1$
$g_{12} = -g_{21}$	$\begin{vmatrix} g_{11} & g_{12} \\ g_{21} & g_{22} \end{vmatrix} = 1$

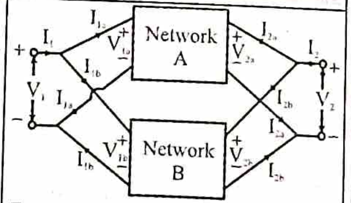
❑ Connections of Two-port networks

Series series connection


I_1
I_{1a}
I_{2a}
I_2
V_{1a}
Network A
V_{2a}
V_1
V_2
I_{1a}
I_{2a}
I_{1b}
I_{2b}
V_{1b}
Network B
V_{2b}
I_{1b}
I_{2b}

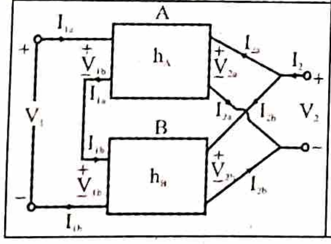
$$\begin{bmatrix} Z_{11} & Z_{12} \\ Z_{21} & Z_{22} \end{bmatrix} = \begin{bmatrix} Z_{11a}+Z_{11b} & Z_{12a}+Z_{12b} \\ Z_{21a}+Z_{21b} & Z_{22a}+Z_{22b} \end{bmatrix}$$

Parallel Parallel connection

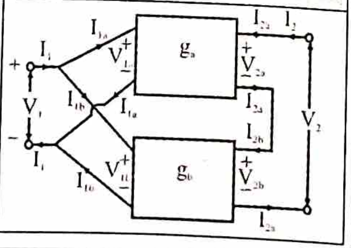

I_1
I_{1a}
V_{1a}
Network A
V_{2a}
I_{2a}
I_2
V_1
I_{1b}
I_{1a}
I_{2b}
I_{2a}
V_2
V_{1b}
Network B
V_{2b}
I_{1b}
I_{2b}

$$\begin{bmatrix} Y_{11} & Y_{12} \\ Y_{21} & Y_{22} \end{bmatrix} = \begin{bmatrix} Y_{11a}+Y_{11b} & Y_{12a}+Y_{12b} \\ Y_{21a}+Y_{21b} & Y_{22a}+Y_{22b} \end{bmatrix}$$

Series parallel connection


A
I_{1a}
V_{1a}
h_A
V_{2a}
I_{2a}
I_2
V_1
I_{1a}
I_{2b}
I_{2a}
V_2
B
I_{1b}
V_{1b}
h_B
V_{2b}
I_{2b}
I_{1b}

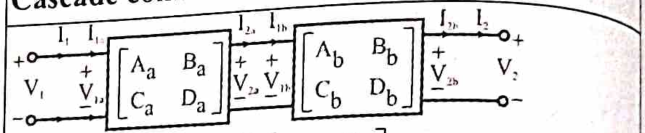
Parallel series connection


I_{1a}
I_{2a}
I_2
I_1
V_{1a}
g_a
V_{2a}
V_1
I_{1b}
I_{1a}
I_{2a}
V_2
I_1
I_{1b}
V_{1b}
g_b
I_{2b}
V_{2b}
I_{2b}

$$\begin{bmatrix} h_{11} & h_{12} \\ h_{21} & h_{22} \end{bmatrix} = \begin{bmatrix} h_{11a}+h_{11b} & h_{12a}+h_{12b} \\ h_{21a}+h_{21b} & h_{22a}+h_{22b} \end{bmatrix}$$

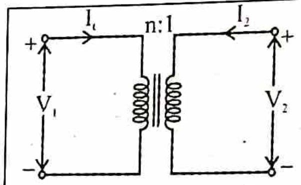
$$\begin{bmatrix} g_{11} & g_{12} \\ g_{21} & g_{22} \end{bmatrix} = \begin{bmatrix} g_{11a}+g_{11b} & g_{12a}+g_{12b} \\ g_{21a}+g_{21b} & g_{22a}+g_{22b} \end{bmatrix}$$

Cascade connection


I_1
I_{1a}
I_{2a}
I_{1b}
I_{2b}
I_2
V_1
V_{1a}
A_a B_a
C_a D_a
V_{2a}
V_{1b}
A_b B_b
C_b D_b
V_{2b}
V_2

$$\begin{bmatrix} A & B \\ C & D \end{bmatrix} = \begin{bmatrix} A_a & B_a \\ C_a & D_a \end{bmatrix} \begin{bmatrix} A_b & B_b \\ C_b & D_b \end{bmatrix}$$

- **Transformer**

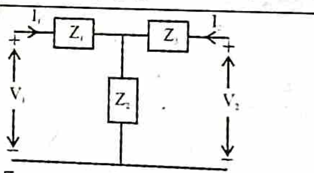

I_1
n:1
I_2
V_1
V_2

$$\begin{bmatrix} A & B \\ C & D \end{bmatrix} = \begin{bmatrix} n & 0 \\ 0 & 1/n \end{bmatrix} = \text{T- parameter}$$

$$\begin{bmatrix} h_{11} & h_{12} \\ h_{21} & h_{22} \end{bmatrix} = \begin{bmatrix} 0 & n \\ -n & 0 \end{bmatrix} = \text{h- parameter}$$

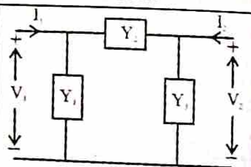
- **T & π Network**

T - Network


I_1
Z_1
Z_3
I_2
V_1
Z_2
V_2

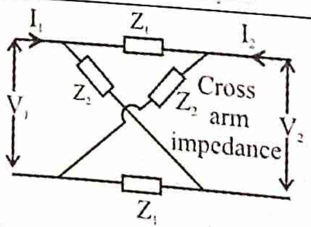
$$\begin{bmatrix} Z_{11} & Z_{12} \\ Z_{21} & Z_{22} \end{bmatrix} = \begin{bmatrix} Z_1+Z_2 & Z_2 \\ Z_2 & Z_2+Z_3 \end{bmatrix}$$

π - Network


I_1
Y_2
I_2
V_1
Y_1
Y_3
V_2

$$\begin{bmatrix} Y_{11} & Y_{12} \\ Y_{21} & Y_{22} \end{bmatrix} = \begin{bmatrix} Y_1+Y_2 & -Y_2 \\ -Y_2 & Y_2+Y_3 \end{bmatrix}$$

- **Lattice Network**


I_1
Z_1
I_2
Z_2
Z_2
Cross arm impedance
V_1
V_2
Z_1

For a symmetrical and reciprocal lattice network-

$$= \begin{bmatrix} \dfrac{Z_1+Z_2}{2} & \dfrac{Z_2-Z_1}{2} \\ \dfrac{Z_2-Z_1}{2} & \dfrac{Z_1+Z_2}{2} \end{bmatrix}$$

❑ AC Circuit Analysis

- **Average and RMS value of periodic signals**

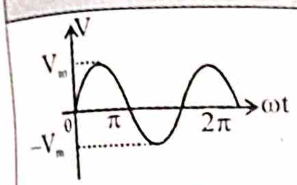
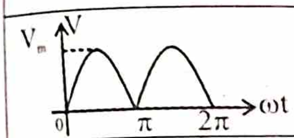
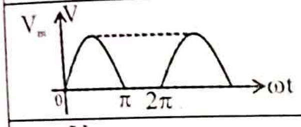
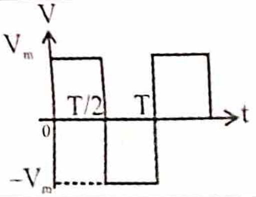
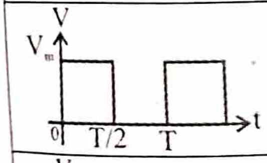
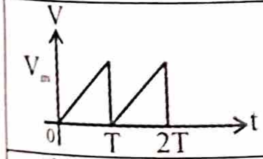
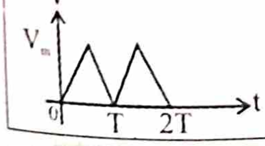
Average value = DC value	$V_{avg} = V_{DC} = \dfrac{1}{T}\int_0^T v(t)\,dt$ • Any function whose cycle is repeated continuously. • Symmetrical AC signal, average value equal to zero.

RMS value	$V_{rms} = \sqrt{\frac{1}{T}\int_0^T v^2(t)\,dt}$ If $f(t) = a_0 + a_1\cos\omega t + a_2\cos 2\omega t + \ldots\ldots + b_1\sin\omega t$ $f(t)_{RMS} = \sqrt{a_0^2 + \frac{1}{2}(a_1^2 + a_2^2 + \ldots . + b_1^2)}$

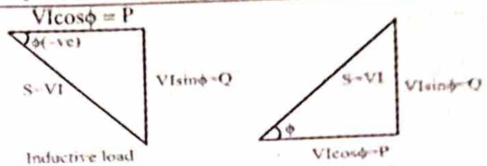
- **Some factor of AC signal**

Peak factor	$P.F. = \frac{V_{max}}{V_{rms}}$
Form factor	$F.F. = \frac{V_{rms}}{V_{avg}}$

- **RMS and Average of Signal**

Time domain Signal	RMS value	Average Value
	$V_{rms} = \frac{V_m}{\sqrt{2}}$	$V_{avg} = \frac{2V_m}{\pi}$
	$V_{rms} = \frac{V_m}{\sqrt{2}}$	$V_{avg} = \frac{2V_m}{\pi}$
	$V_{rms} = \frac{V_m}{2}$	$V_{avg} = \frac{V_m}{\pi}$
	$V_{rms} = V_m$	$V_{avg} = V_m$
	$V_{rms} = \frac{V_m}{\sqrt{2}}$	$V_{avg} = \frac{V_m}{2}$
	$V_{rms} = \frac{V_m}{\sqrt{3}}$	$V_{avg} = \frac{V_m}{2}$
	$V_{rms} = \frac{V_m}{\sqrt{3}}$	$V_{avg} = \frac{V_m}{2}$

❑ Power in AC Sinusoidal Signal

Instantaneous power	$P = V_{rms}I_{rms}\cos\phi$ $= \frac{1}{2}V_m I_m \cos\phi$ In a purely resistive circuit $\phi = 0$ In a pure capacitive circuit $\phi = 90°$(lead) In a pure inductive circuit $\phi = 90°$ (lag)
Apparent power	$S = VI$ unit = VA
Reactive power	$Q = VI\sin\phi$ unit = VAR other name- Wattless power, Quadrature power
Complex power	$S = VI^* = P \pm jQ$ +Q indicates lagging reactive power. –Q indicates leading reactive power.
Power triangle	 VIcosφ = P φ(–ve) S=VI VIsinφ=Q Inductive load S=VI VIsinφ=Q φ VIcosφ=P Capacitive load
Power factor	It is the cosine of the angle between the voltage and current in any ac circuit. $\cos\phi = \frac{R}{Z}$ or $\cos\phi = \frac{P}{S} = \frac{\text{Watt}}{\text{VA}}$

❑ Single Phase AC Circuit

- **Series circuit**

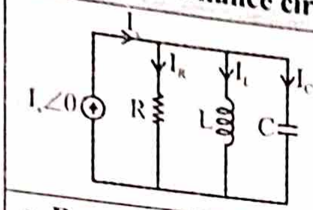
RL	RC	RLC
$V_{RL} = \sqrt{V_R^2 + V_L^2}$ $V_R = IR$ $V_L = IX_L\angle 90^0$ $Z = R + jX_L$	$V_{RC} = \sqrt{V_R^2 + V_C^2}$ $V_R = IR$ $V_C = IX_C\angle -90^0$ $Z = R - jX_C$	$V = \sqrt{V_R^2 + (V_L - V_C)^2}$ $Z = R + j(X_L - X_C)$
$\phi = \tan^{-1}\frac{V_L}{V_R}$	$\phi = \tan^{-1}\left(\frac{-V_C}{V_R}\right)$ $= \tan^{-1}\frac{-X_C}{R}$	$\phi = \tan^{-1}\frac{V_L - V_C}{V_R}$ $\phi = \tan^{-1}\left(\frac{Q_L - Q_C}{P}\right)$
$\cos\phi = \frac{V_R}{V}$(lag)	$\cos\phi = \frac{V_R}{V}$ (lead)	$\cos\phi = \frac{V_R}{V}$ If $V_L > V_C$(lag) $V_C > V_L$(lead) If $V_L = V_C$ (Resonance) $\cos\phi = 1$

- **Parallel Circuit-**

RL	RC	RLC
$I = \sqrt{I_R^2 + I_L^2}$ $I_R = \frac{V}{R}, I_L = \frac{V}{X_L}\angle -90^0$	$I = \sqrt{I_R^2 + I_C^2}$ $I_C = \frac{V}{X_C}\angle 90^0$	$I = \sqrt{I_R^2 + (I_C - I_L)^2}$ $Y = G + j(B_C - B_L)$
$\cos\phi = \frac{I_R}{I}$ (lag) $\cos\phi = \frac{G}{Y}$	$\cos\phi = \frac{I_R}{I}$ (lead)	$\cos\phi = \frac{I_R}{I}$ (Lead); $I_C > I_L$ (Lag); $I_L > I_C$ $\cos\phi = 1$; $I_L = I_C$

❑ Resonance Circuit

Parallel Resonance circuit



- **Resonance condition** $|I_L| = |I_C|$

- **Resonance current**

- $\downarrow I_s = \frac{V}{R} = \frac{V}{Z\uparrow} = I_R = \text{minimum}$

- **Resonance impedance**

$Z = R = \text{maximum}$, $Y = \text{minimum}$

- **Resonance Frequency**

$$f_0 = \frac{1}{2\pi\sqrt{LC}}\text{Hz}$$

ω	Power factor	Y (Admittance)
$\omega < \omega_0$	lag	Inductive
$\omega > \omega_0$	lead	Capacitive
$\omega = \omega_0$	Unity power factor	Resistive

$$\omega_1 = -\frac{1}{2RC} + \sqrt{\left(\frac{1}{2RC}\right)^2 + \frac{1}{LC}},\ \omega_2 = \frac{1}{2RC} + \sqrt{\left(\frac{1}{2RC}\right)^2 + \frac{1}{LC}}$$

$\omega_0 = \sqrt{\omega_1\ \omega_2}$ rad/sec $\qquad f_0 = \sqrt{f_1\ f_2}$ Hz

Where, ω_2 = Upper frequency, ω_1 = Lower frequency

- **Band Width**

$$B.W = \omega_2 - \omega_1 = \frac{1}{RC} = \frac{\omega_0}{\omega_0 RC} = \frac{\omega_0}{Q}$$

$$\omega_1 = \omega_0 - \frac{\Delta\omega}{2},\quad \omega_2 = \omega_0 + \frac{\Delta\omega}{2}$$

- **Power at half power frequency -**

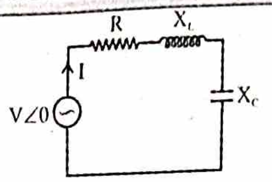
$$P \geq 2P_{\min}, I \geq \sqrt{2}\ I_{\min},\ Y = \frac{\sqrt{2}}{R}$$

- **Quality factor**

$$Q.F. = 2\pi\left(\frac{\text{Maximum energy stored in the circuit}}{\text{Total energy dissipated by the circuit}}\right)$$

$$Q = \frac{R}{X_L} = \frac{R}{X_C} = \omega_0 CR = R\sqrt{\frac{C}{L}} = \frac{|I_L|}{I} = \frac{|I_C|}{I} = \frac{\omega_0}{B.W}$$

Series Resonance Circuit



- **Resonance Condition** $X_C = X_L$, $|V_L| = |V_C|$

- **Resonance current**

$\uparrow I = \frac{V}{R} = \frac{V}{Z\downarrow} = \text{maximum}$

- **Resonance impedance**

$Z = R = \text{minimum}$, $Y = \text{maximum}$

- **Resonance Frequency**

$\omega_0 = \frac{1}{\sqrt{LC}}\text{rad/sec} \qquad f_0 = \frac{1}{2\pi\sqrt{LC}}\text{Hz}$

ω	Power factor	Z (Impedance)
$\omega < \omega_0$	lead	Capacitive
$\omega > \omega_0$	lag	Inductive
$\omega = \omega_0$	Unity power factor	Resistive

$$\omega_1 = -\frac{R}{2L} + \sqrt{\left(\frac{R}{2L}\right)^2 + \frac{1}{LC}},\ \omega_2 = \frac{R}{2L} + \sqrt{\left(\frac{R}{2L}\right)^2 + \frac{1}{LC}}$$

$\omega_0 = \sqrt{\omega_1\ \omega_2}$ rad/sec $\qquad f_0 = \sqrt{f_1\ f_2}$ Hz

$$\omega_C = \omega_0\sqrt{1 - \frac{R^2C}{2L}},\quad \omega_L = \frac{\omega_0}{\sqrt{1 - \frac{R^2C}{2L}}}$$

- **Band Width**

$$\Delta\omega = B.W = \frac{R}{L} = \omega_2 - \omega_1 = \frac{\omega_0}{Q}$$

$$\omega_2 = \omega_0 + \frac{\Delta\omega}{2},\quad \omega_1 = \omega_0 - \frac{\Delta\omega}{2}$$

- **Power at half power frequency-**

$$P \geq \frac{P_{\max}}{2}, I \geq \frac{I_{\max}}{\sqrt{2}},\ Z = \sqrt{2}R$$

- **Quality factor**

$$Q = \frac{|V_L|}{V} = \frac{|V_C|}{V} = \frac{X_L}{R} = \frac{X_C}{R} = \frac{1}{R}\sqrt{\frac{L}{C}} = \frac{\omega_0 L}{R} = \frac{1}{\omega_0 CR}$$

- **Properties**
- It is current magnifier circuit.
- It is also called rejecter circuit
- At resonance Z=R and $Z = \frac{L}{CR}$ (dynamic impedance)
- circuit becomes purely resistive circuit
- A parallel resonance circuit behave as - band stop filter

- **Selectivity** $= \frac{\text{Resonance frequency}}{\text{Bandwidth}}$

• Series RL parallel C circuit

$$\omega_0 = \sqrt{\frac{1}{LC} - \left(\frac{R}{L}\right)^2}$$

• Series RL with parallel RC series circuit

$$\omega = \frac{1}{\sqrt{LC}}\sqrt{\frac{R_L^2 - \frac{L}{C}}{R_C^2 - \frac{L}{C}}} \text{ rad/sec}$$

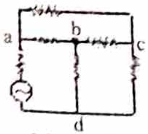
- Dynamic impedance $Z = \frac{L}{CR}$
- Quality Factor (Q.F.) $= \frac{1}{R}\sqrt{\frac{L}{C}}$
- Damping ratio $= \frac{1}{2R}\sqrt{\frac{L}{C}} = \frac{1}{2Q} = \frac{BW}{2\omega_0}$

❑ Three Phase System

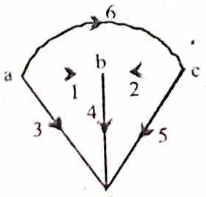
In star connection	In Delta Connection
$i_R + i_Y + i_B = 0$; $I_L = I_{Ph}$ $V_L = \sqrt{3}V_{Ph}$; $V_{Ph} = \frac{V_L}{\sqrt{3}}$	$V_R + V_Y + V_B = 0$ $V_L = V_{Ph}$ $I_L = \sqrt{3}\, I_{Ph}$
$P = 3V_{Ph}I_{Ph}\cos\phi$ or $P = \sqrt{3}\, V_L I_L \cos\phi$ • Line voltage are 30^0 leading from the corresponding phase voltage.	$P = \sqrt{3}V_L I_L \cos\phi$ • Line currents are lagging by 30^0 from their corresponding phase currents.

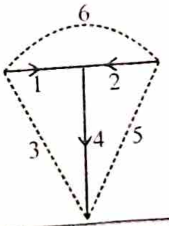
❑ Graph Theory

- ➢ Graph is defined as collection of node and branch
- ➢ Rank of graph = N–1 Where N= Number of node
- ➢ Degree of node = number of incoming branch at any node.



Network





Terminology	Definition	Notation	Formula
Node	End point of branch	[a,b,c,d]	N
Branch	The portion of circuit between two nodes. Number of node pair.	[1,2,3,4,5,6]	N(N-1)/2
Tree	The part of graph containing all nodes. Possible trees = det[[A_r][A_r]^T]	[a,b,c,d]	N^{N-2}
Twig	The branches of a tree are twig	[1,2,4]	N–1
Co-tree	The part of graph is not covered by tree	[3,5,6]	B–N+1
Link or chord	The branch of a co-tree	[3,5,6]	B–N+1
Where N= Number of node, B = Number of branch			

- **Properties**
- Net reactive power of a series resonant circuit is zero. $|P_{LC}| = 0$
- It is also called accepter circuit.
- Net reactive voltage of series resonant circuit is zero. $|V_{LC}| = 0$
- Series resonance circuit is voltage magnifier circuit.

- Quality factor $\propto \frac{1}{\text{power factor}} \propto \frac{1}{B.W}$

- **Incidence Matrix**

$$\begin{array}{c|c} & \text{Branch} \\ \text{Nodes} & \begin{array}{cccccc} 1 & 2 & 3 & 4 & 5 & 6 \end{array} \\ \begin{array}{c} a \\ b \\ c \\ d \end{array} & \begin{bmatrix} 1 & 0 & 1 & 0 & 0 & 1 \\ -1 & -1 & 0 & 1 & 0 & 0 \\ 0 & 1 & 0 & 0 & 1 & -1 \\ 0 & 0 & -1 & -1 & -1 & 0 \end{bmatrix} \end{array}$$

- ➢ Rank of incidence matrix = N-1
- ➢ Order of incidence matrix $[A]_{N\times B}$
- ➢ Sum of the elements of any column is zero

- **Reduced Incidence Matrix**

On deleting any row we get reduced incidence matrix.

$$\begin{array}{c|c} & \text{Branch} \\ \text{Nodes} & \begin{array}{cccccc} 1 & 2 & 3 & 4 & 5 & 6 \end{array} \\ \begin{array}{c} a \\ b \\ c \end{array} & \begin{bmatrix} 1 & 0 & 1 & 0 & 0 & 1 \\ -1 & -1 & 0 & 1 & 0 & 0 \\ 0 & 1 & 0 & 0 & 1 & -1 \end{bmatrix} \end{array}$$

- ➢ Order of reduce incidence matrix = $[R]_{(N-1)\times B}$

- **Tie-set matrix-**

- ➢ Tie-set matrix is a fundamental loop matrix containing only one link and number of twigs
- ➢ Rank of tie-set matrix = B–N+1
- ➢ Number of KVL equation = Number of fundamental loop current = Number of links

- **Cut set matrix-**

> Cut set matrix is a twig dependent matrix having only one twig and number of links.
> Number of cut set (T) = N–1
> Rank of cut set matrix = N–1
> Order of cut set matrix = [Cut set matrix]$_{T\times B}$

❑ Principle of Duality

Resistance (R)	Conductance (G)
Inductance (L)	Capacitance (C)
Impedance (Z)	Admittance (Y)
Voltage (V)	Current (I)
Voltage Source	Current Source
Node	Mesh
Series path	Parallel path
Open circuit	Short circuit
KCL	KVL
Thevenin	Norton
Star Network	Delta Network
Ri (t)	GV (t)
$\frac{Ldi(t)}{dt}$	$C\frac{dv(t)}{dt}$
$\frac{1}{C}\int i(t)dt$	$\frac{1}{L}\int v(t).dt$
V D R	C D R
V_{oc}	I_{sc}

❑ Network Synthesis

- **Condition for physically realisable and stability of a network –**

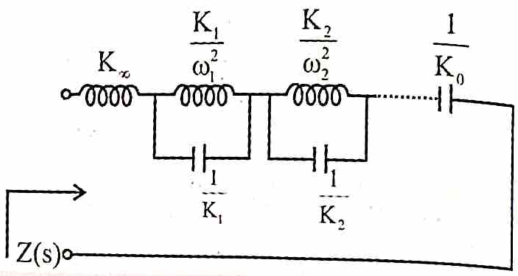
Physically realisable	• All the element value must be positive • All the pole must lie in the left half of the s-plane. $F(s)=\frac{\text{Numerator of polynomial}}{\text{Denominator of polynomial}}$
For stability	• The output of the network must be finite for the finite input. • F(s) can not have poles in the right half of the s-plane. • F(s) can not have multiple poles on the jω axis. • The degree of numerator of the network function f(s) can not exceed the degree of denominator by more than unity. • Any stable network will always be a physically realisible network but it is reverse may not be true.

- **Hurwitz Polynomial –**
- This represents the denominator polynomial of a stable and physically realizable network function.
- No term in a polynomial must be missing unless all the even or odd part are missing.
- This polynomial represents whether all the poles of the network function lie in left half of s-plane or not.
- If any polynomial have only even or odd parts is Hurwitz when $\frac{P(s)}{P'(s)}$ has all positive quotient term.
- If $P(s) = P'(s)\,P''(s)$ is Hurwitz when the polynomial P'(s) and P''(s) are individually Hurwitz.

❑ Synthesis of Network function –

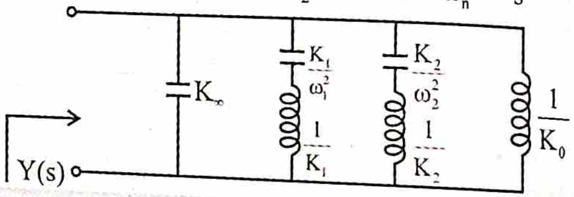
- **Foster - I Realization**

$$Z(s)=K_{\infty}s+\frac{K_1s}{s^2+\omega_1^2}+\frac{K_2s}{s^2+\omega_2^2}+\ldots.+\frac{K_ns}{s^2+\omega_n^2}+\frac{K_0}{s}$$



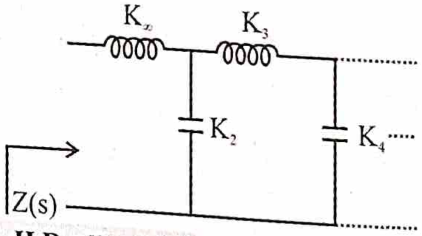
- **Foster - II Realization –**

$$Y(s)=K_{\infty}s+\frac{K_1s}{s^2+\omega_1^2}+\frac{K_2s}{s^2+\omega_2^2}+\ldots.+\frac{K_ns}{s^2+\omega_n^2}+\frac{K_0}{s}$$



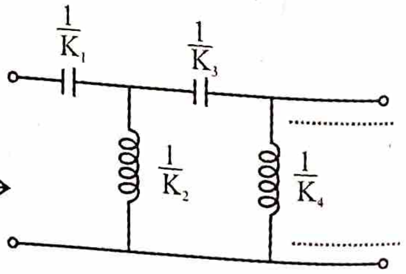
- **Cauer - I Realization –**

$$Z(s)=K_{\infty}s+\cfrac{1}{K_2s+\cfrac{1}{K_3s+\ldots.}}$$



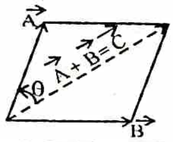
- **Cauer - II Realization –**

$$Z(s)=\frac{K_1}{s}+\cfrac{1}{\cfrac{K_2}{s}+\cfrac{1}{\cfrac{K_3}{s}}\ldots.}$$



ELECTROMAGNETIC FIELD THEORY

❑ Vector analysis-



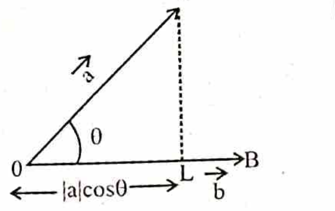
Addition	$\boxed{\vec{A}+\vec{B}=\vec{C}}$
Subtraction	$\boxed{\vec{A}-\vec{B}=\vec{A}+(-\vec{B})}$
Commutative law	$\boxed{\vec{A}+\vec{B}=\vec{B}+\vec{A}}$
Associative law	$(\vec{A}+\vec{B})+\vec{C}=\vec{A}+(\vec{B}+\vec{C})$

■ Multiplication

Scalar or Dot product	$\boxed{\vec{A}.\vec{B}=\lvert A\rvert\lvert B\rvert\cos\theta}$
Vector or cross product	$\boxed{\vec{A}\times\vec{B}=\lvert A\rvert\lvert B\rvert\sin\theta\,\hat{a}_n}$ θ = angle between $\vec{A}$ and $\vec{B}$ $\hat{a}_n$ = Unit vector perpendicular to $\vec{A}$ and $\vec{B}$
Scalar triple product	$\boxed{\vec{A}\cdot(\vec{B}\times\vec{C})=\vec{B}\cdot(\vec{C}\times\vec{A})=\vec{C}\cdot(\vec{A}\times\vec{B})}$
Vector triple product	$\boxed{\vec{A}\times(\vec{B}\times\vec{C})=\vec{B}(\vec{A}\cdot\vec{C})-\vec{C}(\vec{A}\cdot\vec{B})}$

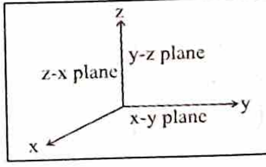
- **Unit vector** $\boxed{\hat{r}=\dfrac{\vec{r}}{\lvert\vec{r}\rvert}=\dfrac{x\hat{a}_x+y\hat{a}_y+z\hat{a}_z}{\sqrt{x^2+y^2+z^2}}}$

- **Projection of a vector**

	Projection of vector $\bar{a}$ on vector $\vec{b}=\dfrac{\bar{a}.\vec{b}}{\lvert\vec{b}\rvert}$ Projection of vector $\vec{b}$ on vector $\bar{a}=\dfrac{\bar{a}.\vec{b}}{\lvert\bar{a}\rvert}$

❑ Co-ordinate System

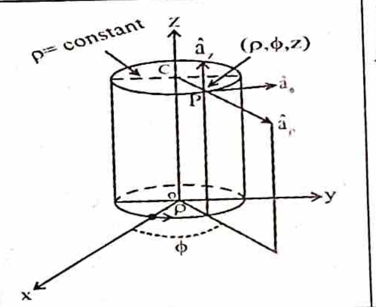
■ Cartesian Co-ordinate System (x, y, z)

	$-\infty\le x\le+\infty$ $-\infty\le y\le+\infty$ $-\infty\le z\le+\infty$

Unit vector cross product	Unit vector dot product
$\hat{a}_x\times\hat{a}_y=\hat{a}_z$	$\hat{a}_x.\hat{a}_y=\hat{a}_y.\hat{a}_z=\hat{a}_z.\hat{a}_x=0$
$\hat{a}_y\times\hat{a}_z=\hat{a}_x$	$\hat{a}_x.\hat{a}_x=\hat{a}_y.\hat{a}_y=\hat{a}_z.\hat{a}_z=1$
$\hat{a}_z\times\hat{a}_x=\hat{a}_y$	
$\hat{a}_x\times\hat{a}_x=\hat{a}_y\times\hat{a}_y=\hat{a}_z\times\hat{a}_z=0$	

Position vector	$\boxed{\vec{r}=x\hat{a}_x+y\hat{a}_y+z\hat{a}_z}$
Displacement vector	$\boxed{\vec{d\ell}=dx\,\hat{a}_x+dy\,\hat{a}_y+dz\,\hat{a}_z}$ $\boxed{\lvert\vec{d\ell}\rvert=\sqrt{(dx)^2+(dy)^2+(dz)^2}}$
Differential normal surface area	$d\vec{S}_x=dydz\hat{a}_x$, $d\vec{S}_y=dzdx\hat{a}_y$ $d\vec{S}_z=dxdy\hat{a}_z$
Differential volume	$dV=dxdydz$

■ Cylindrical Co-ordinate system (ρ,ϕ,z)

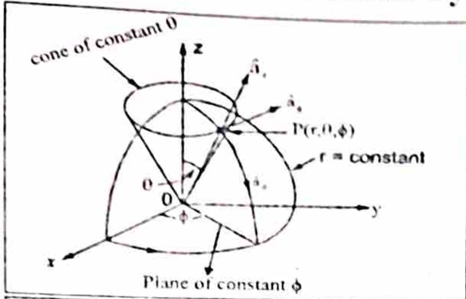
	$\begin{cases}0\le\rho<\infty\\0\le\phi<2\pi\\-\infty<z<\infty\end{cases}$

Position vector of a point p (ρ,ϕ,z)	$\boxed{\vec{r}=\rho\hat{a}_\rho+\phi\hat{a}_\phi+z\hat{a}_z}$
Displacement vector	$\boxed{\vec{d\ell}=d\rho\hat{a}_\rho+\rho d\phi\hat{a}_\phi+dz\hat{a}_z}$ $\boxed{\lvert\vec{d\ell}\rvert=\sqrt{(d\rho)^2+(\rho d\phi)^2+(dz)^2}}$
Differential length element	$\boxed{d\rho\hat{a}_\rho,\ \rho d\phi\hat{a}_\phi,\ dz\hat{a}_z}$
Differential normal surface areas	$d\vec{S}_\rho=\rho d\phi dz\hat{a}_\rho$, $d\vec{S}_\phi=d\rho dz\hat{a}_\phi$ $d\vec{S}_z=\rho d\phi d\rho\hat{a}_z$
Differential volume	$\boxed{dV=\rho d\rho d\phi dz}$

- **Comparison between Cartesian and cylindrical co-ordinate system**

Cylindrical to Cartesian	$x=\rho\cos\phi$, $y=\rho\sin\phi$ $z=z$
Cartesian to cylindrical	$\rho=\sqrt{x^2+y^2}$ $\phi=\tan^{-1}\left(\dfrac{y}{z}\right)$, $z=z$

Spherical Co-ordinate System (r, θ, ϕ)

 cone of constant θ z $\hat{a}_r$ $\hat{a}_\phi$ P(r,θ,ϕ) r = constant θ 0 ϕ $\hat{a}_\theta$ y x Plane of constant ϕ	$\begin{cases} 0 \le r \le \infty \\ 0 \le \theta \le \pi \\ 0 \le \phi \le 2\pi \end{cases}$

Position vector of point p	$\boxed{\vec{r} = r\hat{a}_r}$
Displacement vector	$\boxed{d\vec{\ell} = dr\hat{a}_r + rd\theta\hat{a}_\theta + r\sin\theta d\phi\hat{a}_\phi}$ $\boxed{\lvert d\vec{\ell}\rvert = \sqrt{(dr)^2 + (rd\theta)^2 + (r\sin\theta d\phi)^2}}$
Differential length element	$\boxed{dr\hat{a}_r,\ rd\theta\hat{a}_\theta,\ r\sin\theta d\phi\hat{a}_\phi}$
Differential normal surface area	$d\vec{S}_r = r^2\sin\theta d\theta d\phi\hat{a}_r$ $d\vec{S}_\theta = r\sin\theta dr d\phi\hat{a}_\theta$, $d\vec{S}_\phi = r dr d\theta\hat{a}_\phi$
Differential volume	$\boxed{dV = r^2\sin\theta dr d\theta d\phi}$

- **Relation between spherical and Cartesian Co-ordinate system**

Spherical to Cartesian	$x = r\sin\theta\cos\phi$ $y = r\sin\theta\sin\phi$ $z = r\cos\theta$
Cartesian to Spherical	$r = \sqrt{x^2 + y^2 + z^2}$ $\phi = \tan^{-1}\frac{y}{x}$ $\theta = \tan^{-1}\frac{\sqrt{x^2+y^2}}{z}$

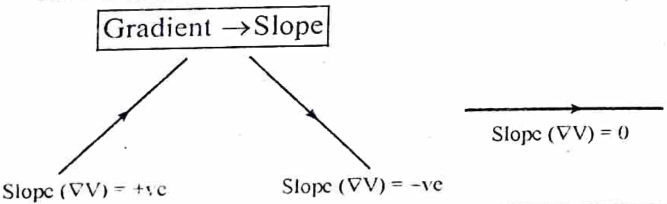
Special Derivatives

- **Del (∇) Operator-**

In Cartesian co-ordinate system	$\boxed{\nabla = \frac{\partial}{\partial x}\hat{a}_x + \frac{\partial}{\partial y}\hat{a}_y + \frac{\partial}{\partial z}\hat{a}_z}$
In Cylindrical co-ordinate system	$\boxed{\nabla = \frac{\partial}{\partial \rho}\hat{a}_\rho + \frac{1}{\rho}\frac{\partial}{\partial \phi}\hat{a}_\phi + \frac{\partial}{\partial z}\hat{a}_z}$
In spherical co-ordinate system	$\boxed{\nabla = \frac{\partial}{\partial r}\hat{a}_r + \frac{1}{r}\frac{\partial}{\partial \theta}\hat{a}_\theta + \frac{1}{r\sin\theta}\frac{\partial}{\partial \phi}\hat{a}_\phi}$

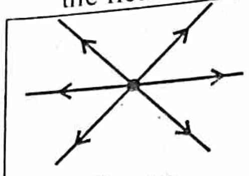
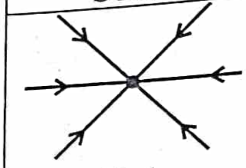
- **Gradient of a Scalar field**
  Gradient of scalar field represents the both magnitude and the direction of the maximum space rate of increase of a scalar.

$\boxed{\text{Gradient} \rightarrow \text{Slope}}$



In Cartesian co-ordinate system	$\boxed{\nabla V = \frac{\partial V}{\partial x}\hat{a}_x + \frac{\partial V}{\partial y}\hat{a}_y + \frac{\partial V}{\partial z}\hat{a}_z}$
In cylindrical co-ordinate system	$\boxed{\nabla V = \frac{\partial V}{\partial \rho}\hat{a}_\rho + \frac{1}{\rho}\frac{\partial V}{\partial \phi}\hat{a}_\phi + \frac{\partial V}{\partial z}\hat{a}_z}$
In spherical co-ordinate system	$\boxed{\nabla V = \frac{\partial V}{\partial r}\hat{a}_r + \frac{1}{r}\frac{\partial V}{\partial \theta}\hat{a}_\theta + \frac{1}{r\sin\theta}\frac{\partial V}{\partial \phi}\hat{a}_\phi}$

➢ **Divergence of a vector-** Divergence explains how the field behaves towards or away from a point.

 Source	$\nabla.\vec{A} = +ve$ Going away from a point in different direction.
 Sink	$\nabla.\vec{A} = -ve$ Coming towards the point from the different direction
↑↑↑↑ • ↑↑↑↑	$\nabla.\vec{A} = 0$ Divergence- less or solenoidal

$$\boxed{\text{Div}\vec{A} = \nabla.\vec{A} = \lim_{\nabla V \to 0}\frac{\oint_s \vec{A}.d\vec{S}}{\Delta V}}$$

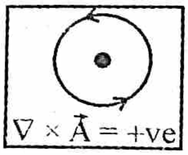
In cartesian co-ordinate system	$\boxed{\nabla.\vec{D} = \frac{\partial D_x}{\partial x} + \frac{\partial D_y}{\partial y} + \frac{\partial D_z}{\partial z}}$
In cylindrical co-ordinate system	$\boxed{\nabla.\vec{D} = \frac{1}{\rho}\frac{\partial}{\partial \rho}(\rho D_\rho) + \frac{1}{\rho}\frac{\partial D_\phi}{\partial \phi} + \frac{\partial D_z}{\partial z}}$

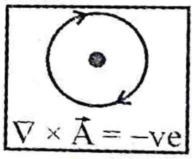
➢ In spherical co-ordinate system

$$\boxed{\nabla.\vec{D} = \frac{1}{r^2}\frac{\partial}{\partial r}(r^2 D_r) + \frac{1}{r\sin\theta}\frac{\partial}{\partial \theta}(\sin\theta D_\theta) + \frac{1}{r\sin\theta}\frac{\partial D_\phi}{\partial \phi}}$$

- **Curl of a Vector field**
  Curl of any vector point function gives the measure of angular velocity at any point of the vector field.

$$\boxed{\nabla \times \vec{A} = \lim_{\Delta S \to 0}\frac{\oint_L \vec{A}.d\vec{\ell}}{\Delta S}\hat{i}_n} \quad \boxed{\text{Curl} \rightarrow \text{rotation}}$$


$\nabla \times \vec{A} = +ve$


$\nabla \times \vec{A} = -ve$

↑↑•↑↑
$\nabla \times \vec{A} = 0$

- **Curl of vector**

Curl in rectangular co-ordinate	$\text{Curl}\vec{A} = \nabla \times \vec{A} = \begin{bmatrix} \hat{a}_x & \hat{a}_y & \hat{a}_z \\ \frac{\partial}{\partial x} & \frac{\partial}{\partial y} & \frac{\partial}{\partial x} \\ A_x & A_y & A_z \end{bmatrix}$

Curl in cylindrical co-ordinate	$\nabla\times\vec{A}=\frac{1}{\rho}\begin{vmatrix}\hat{a}_\rho & \rho\hat{a}_\phi & \hat{a}_z\\ \frac{\partial}{\partial\rho} & \frac{\partial}{\partial\phi} & \frac{\partial}{\partial z}\\ A_\rho & \rho A_\phi & A_z\end{vmatrix}$
Curl in spherical co-ordinate	$\nabla\times\vec{A}=\frac{1}{r^2\sin\theta}\begin{vmatrix}\hat{a}_r & r\hat{a}_\theta & r\sin\theta\hat{a}_\phi\\ \frac{\partial}{\partial r} & \frac{\partial}{\partial\theta} & \frac{\partial}{\partial\phi}\\ A_r & rA_\theta & r\sin\theta A_\phi\end{vmatrix}$

- **Important identities**

$\nabla.\left(\nabla\times\vec{A}\right)=0$	Divergence of curl is always zero.
$\nabla\times(\nabla A)=0$	Curl of gradient is always zero.
$\nabla.\vec{A}=0$	$\vec{A}$ is divergence less or solenoidal
$\nabla\times\vec{A}=0$	$\vec{A}$ is irrotational

- **Laplace operator**

∇^2

Scalar (f)	Vector(f)
$\nabla^2 f$	$\nabla^2\vec{f}$
Scalar Laplacian	Vector Laplacian
$\boxed{\nabla^2 f=\nabla.(\nabla f)}$	$\boxed{\nabla^2\vec{f}=\nabla\left(\nabla.\vec{f}\right)-\nabla\times\nabla\times\vec{f}}$

☞ **Remember point**

If Laplacian of any scalar 'f' is zero in the given region, then that scalar 'f' is said to be harmonic.

In Cartesian co-ordinate system	$\nabla^2 f=\frac{\partial^2 f}{\partial x^2}+\frac{\partial^2 f}{\partial y^2}+\frac{\partial^2 f}{\partial z^2}$
In cylindrical co-ordinate system	$\nabla^2 f=\frac{1}{\rho}\frac{\partial}{\partial\rho}\left(\rho\frac{\partial f}{\partial\rho}\right)+\frac{1}{\rho^2}\frac{\partial^2 f}{\partial\phi^2}+\frac{\partial^2 f}{\partial z^2}$

In spherical co-ordinate system

$$\nabla^2 f=\frac{1}{r^2}\frac{\partial}{\partial r}\left(r^2\frac{\partial f}{\partial r}\right)+\frac{1}{r^2\sin\theta}\frac{\partial}{\partial\theta}\left(\sin\theta\frac{\partial f}{\partial\theta}\right)+\frac{1}{r^2\sin^2\theta}\left(\frac{\partial^2 f}{\partial\phi^2}\right)$$

Divergence Theorem	Stoke's Theorem
The divergence of $\vec{A}$ at a point P is the outward flux per unit volume shrinks about P. $\oint_s\vec{A}.d\vec{S}=\int_V\left(\nabla.\vec{A}\right)dV$	The curl is a vector operation that can be used to state, if there is a rotation associated with a vector. $\oint_L\vec{A}.d\vec{\ell}=\iint_S\left(\nabla\times\vec{A}\right).d\vec{S}$

❑ Electrostatics

■ Source of Charges

Line charge density (ρ_L)	$\frac{dQ}{dL}=\rho_L\,(C/m)$, $Q=\int_L\rho_L dL\ C$
Surface charge density (ρ_s)	$\frac{dQ}{dS}=\rho_s\,(C/m^2)$, $Q=\iint_s\rho_s\,dS\ C$
Volume charge density (ρ_s)	$\frac{dQ}{dV}=\rho_v\,(C/m^3)$, $Q=\iiint_v\rho_v dV\ C$

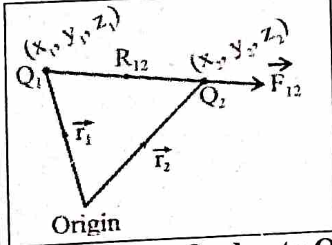
- **Relation between Network theory and electromagnetic field**

Network Theory	EMFT
Voltage (V)-Volt	Electric field intensity $(\vec{E})\frac{\text{Volt}}{m}$
Current (I)-Amp	Magnetic field intensity $(\vec{H})A/m$ Current density $(\vec{J})A/m^2$
Capacitance (C)-Farad	Permittivity (ε) Farad/m
Inductance (L)-Henry	permeability (μ) Henry/m
Charge (Q)-Coulomb	Electric flux density (D)C/m²
Magnetic flux (ϕ) Weber	Magnetic flux density (B)Wb/m²

☞ **Remember Point**

$Q=CV$	$\phi=LI$	$W_C=\frac{1}{2}CV^2$
$\Downarrow$	$\Downarrow$	$\Downarrow$
$\vec{D}=\varepsilon\vec{E}$	$\vec{B}=\mu\vec{H}$	$W_E=\frac{1}{2}\varepsilon\vec{E}^2$

■ Coulomb's Law



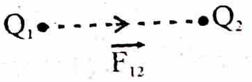
$\boxed{\vec{r}_1=x_1\hat{a}_x+y_1\hat{a}_y+z_1\hat{a}_z}$

$\boxed{\vec{r}_2=x_2\hat{a}_x+y_2\hat{a}_y+z_2\hat{a}_z}$

- **Force on Q₂ due to Q₁**

➢ $\boxed{F_{12}=\frac{1}{4\pi\varepsilon_o}\frac{Q_1Q_2}{\left|\vec{R}_{12}\right|^2}\hat{a}_{R_{12}}=\frac{1}{4\pi\varepsilon_o}\frac{Q_1Q_2}{\left|\vec{R}_{12}\right|^3}\vec{R}_{12}}$

➢ $\boxed{\varepsilon_o=8.854\times10^{-12}F/m=\frac{10^{-9}}{36\pi}}$



➢ $\boxed{\frac{1}{4\pi\varepsilon_o}=K=9\times10^9 m/F}$

➢ If two similar charges with same sign are placed at a distance then the force acted on it is repulsive in nature. $\boxed{\vec{F}_1=-\vec{F}_2}$

- **Electric Field Intensity-** It is measure of strength of electric field at any point. $\boxed{E=\frac{F}{Q}N/C}$

- **Electric field due to point charge**

$$\boxed{\vec{E} = \frac{\vec{F}}{Q} = \frac{Q}{4\pi\varepsilon_o R^2}\hat{a}_R, \text{V/m}}$$

- **Electric field due to various charge distribution:**

For Line charge	$\boxed{E = \int_L \frac{\rho_L dL}{4\pi\varepsilon_o R^2}\hat{a}_R}$ ρ_L = Line Charge Density
For Surface charge	$\boxed{E = \int_S \frac{\rho_s dS}{4\pi\varepsilon_o R^2}\hat{a}_R}$ ρ_S = Surface Charge Density
For Volume charge	$\boxed{E = \int_V \frac{\rho_V dV}{4\pi\varepsilon_o R^2}\hat{a}_R}$ ρ_v = Volume Charge Density
Electric field due to infinite long line charge	$\boxed{\vec{E} = \frac{\rho_L}{2\pi\varepsilon_o\rho}\hat{a}_\rho}$, $\boxed{E \propto \frac{1}{\rho}}$
Electric field on the axis of charged ring	$\boxed{\vec{E} = \frac{\rho_L \hat{a}_z}{2\varepsilon_o\left(z^2+a^2\right)^{3/2}}}$
Electric field due to a charged circular disc	$\boxed{\vec{E} = \frac{\rho_s}{2\varepsilon_o}\left(1-\frac{z}{\sqrt{z^2+a^2}}\right)\hat{a}_z}$
Electric field due to infinite charged sheet	$\boxed{\vec{E} = \frac{\rho_s}{2\varepsilon_o}\hat{a}_n}$
Electric field due to point is below the infinite charged sheet	$\boxed{\vec{E} = \frac{\rho_s}{2\varepsilon_o}(-\hat{a}_n)}$

➢ Electric field at the centre of uniformly charged ring is zero

➢ Electric field due to infinite sheet is independent of distance.

➢ Electric/Displacement flux Density $\boxed{\vec{D} = \varepsilon\vec{E}\ \text{C/m}^2}$

- **Gauss's law** $\boxed{\psi = \oint_S \vec{D}.d\vec{S} = Q = \int_V \rho_V dv}$

➢ Gauss's law in differential or point form $\boxed{\nabla.\vec{D} = \rho_v}$

➢ For charge free region, $\rho_v = 0$, $\boxed{\nabla.\vec{D} = 0}$

- **Energy Density in Electrostatic Field**

➢ Electrostatic Energy Density–

$$\boxed{W_E = \frac{1}{2}\vec{D}.\vec{E} = \frac{1}{2}\varepsilon_o\vec{E}^2 = \frac{D^2}{2\varepsilon_o}}\ \text{J/m}^3$$

➢ Total Electrostatic Energy

$$\boxed{W_E = \frac{1}{2}\int_V \vec{D}.\vec{E}\,dV = \frac{1}{2}\int_V \varepsilon_o E^2 dV = \frac{1}{2}CV^2}$$

- **Electric Potential difference**

$$\boxed{V_{AB} = -\int_A^B \vec{E}.d\vec{\ell} = \frac{Q}{4\pi\varepsilon_o}\left[\frac{1}{r_B} - \frac{1}{r_A}\right]}$$

- **Potential at a point P due to point charge**

$$\boxed{(V) = \frac{Q}{4\pi\varepsilon r}, V = \int_r^\infty \vec{E}.\vec{dl}}$$

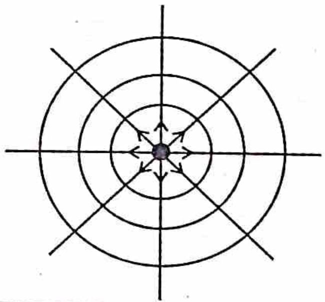
- **Relationship between $\vec{E}$ & V,** $\boxed{\vec{E} = -\nabla V}$
- **Capacitance**

Parallel plate	$C = \frac{\varepsilon_0\varepsilon_r A}{d}$
Co-axial cable	$C = \frac{2\pi\varepsilon L}{\ell n(b/a)}$
Capacitance of sphere	$C = \frac{4\pi\varepsilon}{\left(\frac{1}{a}-\frac{1}{b}\right)} = 4\pi\varepsilon\left(\frac{ab}{b-a}\right)$
Capacitance of isolated sphere	$C = 4\pi\varepsilon a$
Composite parallel plate capacitor	$C = \frac{\varepsilon A}{\frac{d_1}{\varepsilon_{r1}} + \frac{d_2}{\varepsilon_{r2}} + ... + \frac{d_n}{\varepsilon_{rn}}}$

Equipotential Surface

➢ Concentric sphere whose centre is at point charge (source).

➢ Equipotential surface and electric field line are always perpendicular to each other.



Poisson's equation	**Laplace Equation**
$\boxed{\nabla^2 V = \frac{-\rho_V}{\varepsilon}}$	$\boxed{\nabla^2 V = 0}$

- **Electric dipole moment** $\boxed{\vec{p} = Q.\vec{d}}$
- **Inside a Conductor-** $\boxed{E = 0, \rho_V = 0, V_{ab} = 0}$
- **Power (Joule's law)**

$\boxed{P = \int_V \vec{E}.\vec{J}dV}$ J →current density (A/m^2)

- **Continuity Equation** $\boxed{\nabla.J = -\frac{\partial\rho_V}{\partial t}}$
- **Dielectric material -** In any dielectric material electric dipole are present. Dielectric material stores electric energy. The energy gap in the dielectric

material is very large. Dielectric material have negative temperature coefficient of resistance.

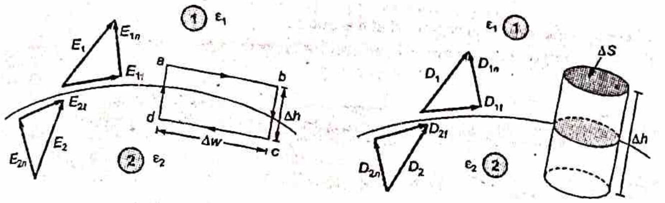
$\bar{D} = \varepsilon_0 \bar{E} + \bar{P}$ → [True for all material]

For linear dielectric material. $\vec{P} = \chi_e \varepsilon_0 \vec{E}$

$\boxed{\bar{D} = (1+\chi_e)\varepsilon_0 \bar{E}}$ and $\boxed{\varepsilon_r = 1+\chi_e}$

Boundary Condition- Boundary condition govern the behaviour of electric field at the boundary between two different media. If field exist in a region consisting of 2 different media then there is some condition which must be satisfy at the interface separating media is known as boundary condition.

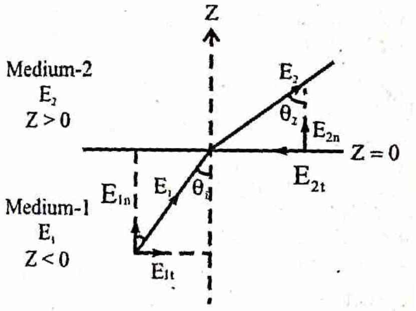
- **Dielectric - Dielectric Interference -**



➢ Tangential component of electric field in medium (1) and medium (2) are equal $\boxed{E_{1t} = E_{2t}}$

➢ If the both medium are equal, then surface charge on the boundary $\boxed{D_{1n} = D_{2n},\ \rho_s = 0}$

➢ The field is directed from medium (1) to medium (2) $\boxed{D_{2n} - D_{1n} = \rho_S}$



$$\because \tan\theta_1 = \frac{E_{1t}}{E_{1n}}$$

$$\tan\theta_2 = \frac{E_{2t}}{E_{2n}}$$

$$\boxed{\frac{\tan\theta_1}{\tan\theta_2} = \frac{E_{1t}}{E_{1n}} \times \frac{E_{2n}}{E_{2t}}}$$

$$\because E_{1t} = E_{2t}$$

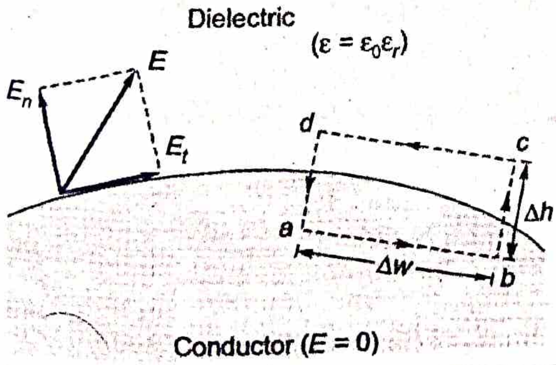
$$\frac{\tan\theta_1}{\tan\theta_2} = \frac{E_{2n}}{E_{1n}}$$

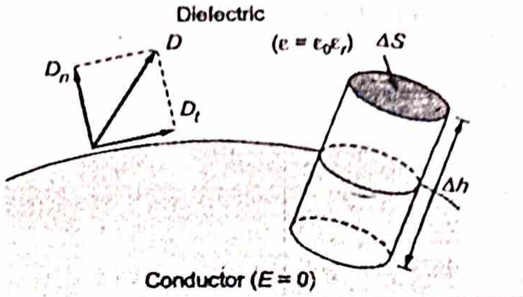
$$\because D_{1n} = D_{2n}, \rho_s = 0$$

$$\varepsilon_1 . E_{1n} = \varepsilon_2 E_{2n}$$

$$\frac{E_{2n}}{E_{1n}} = \frac{\varepsilon_1}{\varepsilon_2}$$

- **Conductor - dielectric boundary**



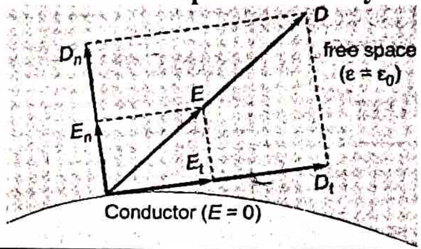


$\boxed{E_t = 0,\ D_t = \varepsilon_0 E_t = 0}$ $\boxed{D_n = \rho_s,\ D_{2n} = \varepsilon_2 E_{2n}}$

- **Law of Refraction**
  From boundary condition

$\vec{E}_{1t} = \vec{E}_{2t}$ or $E_1 \sin\theta_1 = E_2 \sin\theta_2$
$D_{1n} = D_{2n}$ or $\varepsilon_1 E_1 \cos\theta_1 = \varepsilon_2 E_2 \cos\theta_2$
$\frac{\tan\theta_1}{\varepsilon_1} = \frac{\tan\theta_2}{\varepsilon_2}$ or $\frac{\tan\theta_1}{\tan\theta_2} = \frac{\varepsilon_1}{\varepsilon_2}$

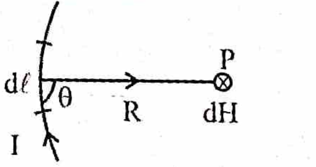
- Image theory is applicable for problem solving of electrostatic field only.
- **Conductor and free space boundary condition**



$E_t = 0,\ D_t = \varepsilon_0 E_t = 0$	$D_n = \rho_s,\ E_n = \frac{\rho_s}{\varepsilon_0}$

❑ Magneto static Field

■ Biot-Savart's law



$$\boxed{d\bar{H} = \oint \frac{Id\ell \times \hat{a}_r}{4\pi R^2} A/m}$$

$$\boxed{dH \propto \frac{Id\ell \sin\theta}{R^2}}$$

Note- Biot-Savert's law is analogous to coulomb's law.

- **Magnetic Field Intensity for Distributed Current Source**

Line current	Surface current	Volume current
$\bar{H} = \int_L \frac{Id\ell \times \hat{a}_r}{4\pi R^2}$	$\bar{H} = \int_S \frac{KdS \times \hat{a}_r}{4\pi R^2}$	$\bar{H} = \int_V \frac{JdV \times \hat{a}_r}{4\pi R^2}$

Note- Ampere's circuital law is analogous to gauss law.

➢ Magnetic field intensity due to straight current carrying filamentary conductor

For finite length	$\bar{H} = \frac{I}{4\pi\rho}(\cos\alpha_2 - \cos\alpha_1)\hat{a}_\phi$
For semi finite length	$\bar{H} = \frac{I}{4\pi\rho}\hat{a}_\phi$
For infinite length	$\bar{H} = \frac{I}{2\pi\rho}\hat{a}_\phi$

- **Relation between μ_0 & ε_0**

$$\boxed{c = \frac{1}{\sqrt{\mu_o \varepsilon_o}} = 3\times10^8\,\text{m/s},\ c = \text{Speed of light}}$$

Note- Speed of light in a media of permittivity ε_r is $\frac{c}{\sqrt{\varepsilon_r}}$

- **Magnetic Energy Density (W_m)**

$$\boxed{W_m = \frac{1}{2}\mu\vec{H}^2 = \frac{1}{2}\vec{B}.\vec{H}}$$

- **Magnetic Energy**

$$\boxed{w_m = \iiint_V W_m dV = \frac{1}{2}LI^2\,(\text{Joule})}$$

- **Force on a charge particle placed in a magnetic field**

Magnetic force	$\boxed{\vec{F}_m = Q\left(\vec{v}\times\vec{B}\right)\ \text{newton}}$
Electric force	$\boxed{\vec{F}_e = Q\vec{E}}$
Lorentz force Equation	$\boxed{\vec{F} = \vec{F}_e + \vec{F}_m = Q\left(\vec{E}+\vec{v}\times\vec{B}\right)}$
Force on a current carrying conductor	$\boxed{\vec{F} = \oint_L I\vec{d\ell}\times\vec{B}}$

➢ Force between 2-infinite line $\boxed{F = \frac{\mu_0 I_1 I_2 \ell}{2\pi d}}$

➢ Same direction current → attraction

➢ Opposite direction current → Repulsion

- **Magnetic Torque**

$$\boxed{\begin{array}{l} T = BIA\sin\alpha \\ \vec{T} = \vec{M}\times\vec{B} \end{array}}\quad A \rightarrow \text{area of the loop}$$

- **Magnetic Dipole Moment** $\boxed{\vec{M} = iA.\hat{n}}$

Maxwell's Equations

- **Maxwell's equation for Static Electric and Magnetic Fields**

	Differential or point form	Integral form	Remarks
First Law	$\vec{\nabla}.\vec{D} = \rho_v$	$\oint_S \vec{D}.d\vec{S} = \int_V \rho_V dv$	Gauss's law
Second Law	$\vec{\nabla}.\vec{B} = 0$	$\oint_S \vec{B}.d\vec{S} = 0$	Non existence of magnetic monopole
Third Law	$\vec{\nabla}\times\vec{E} = 0$	$\oint_L \vec{E}.d\vec{\ell} = 0$	Conservative property of electrostatic field
Fourth Law	$\vec{\nabla}\times\vec{H} = \vec{J}$	$\oint_L \vec{H}.d\vec{\ell} = \int_S \vec{J}.d\vec{S}$	Ampere's circuital law

Note-

(i) $\oint_S \vec{B}.d\vec{S} = 0$ (KCL)

(ii) $\oint_L \vec{E}.d\vec{\ell} = 0$ (KVL)

- **Maxwell's equation for time-varying field**

Differential form or point form	Integral form	Remarks
$\vec{\nabla}.\vec{D} = \rho_v$	$\oint_S \vec{D}.d\vec{S} = \int_V \rho_V dv$	Gauss's law
$\vec{\nabla}.\vec{B} = 0$	$\oint_S \vec{B}.d\vec{S} = 0$	Non existence of magnetic charge
$\vec{\nabla}\times\vec{E} = \frac{-\partial\vec{B}}{dt}$	$\oint_L \vec{E}.d\vec{\ell} = \frac{-\partial}{\partial t}\int_S \vec{B}.d\vec{S}$	Faraday's law
$\vec{\nabla}\times\vec{H} = \vec{J} + \frac{\partial\vec{D}}{\partial t}$	$\oint_L \vec{H}.d\vec{\ell} = \int_S\left(\vec{J}+\frac{\partial\vec{D}}{\partial t}\right).d\vec{S}$	Ampere's circuital law

➢ Vector magnetic potential (A) and magnetic field density relation $\boxed{\vec{B} = \nabla\times\vec{A}}$

- **Time-varying potentials** $\boxed{\vec{E} = -\nabla.V - \frac{\partial A}{\partial t}}$

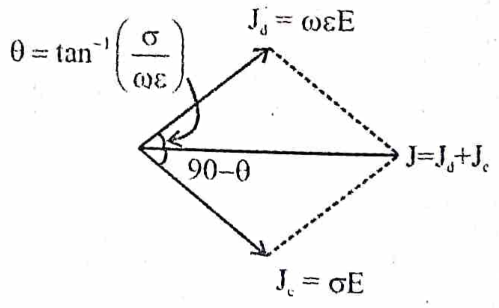
- **Lorentz condition for potential** $\boxed{\nabla.A = -\mu\varepsilon\frac{\partial V}{\partial t}}$

☐ Electromagnetic Wave Propagation

Free space	$\sigma = 0,\ \varepsilon = \varepsilon_o, \mu = \mu_o$
Perfect dielectric	$\sigma = 0$, ε and μ can have any value
Good dielectrics	$\sigma \simeq 0,\ \varepsilon = \varepsilon_r\varepsilon_o, \mu = \mu_r\mu_o$ or $\sigma << \omega\varepsilon$
Perfect conductor	$\sigma \simeq \infty$, ε and μ can have any vlaue
Good conductor	$\sigma \simeq \infty,\ \varepsilon = \varepsilon_o, \mu = \mu_r\mu_o$ or $\sigma >> \omega\varepsilon$
Lossy Dielectric	$\sigma \neq 0,\ \varepsilon = \varepsilon_0\varepsilon_r,\ \mu = \mu_0\mu_r$
For isotopic medium	independent of μ, ε, σ

- **Relation between conduction current density and displacement current density**

$$\nabla\times\vec{H} = \sigma\vec{E} + j\omega\varepsilon\vec{E} = \vec{J}_c + \vec{J}_d$$


$\theta = \tan^{-1}\left(\frac{\sigma}{\omega\varepsilon}\right)$
$J_d = \omega\varepsilon E$
$90-\theta$
$J=J_d+J_c$
$J_c = \sigma E$

$\vec{J}_C = \sigma\vec{E} \rightarrow$ Conduction current density

$\vec{J}_d = \frac{\partial\vec{D}}{dt} \rightarrow$ Displacement current density

$\left|\frac{\vec{J}_c}{\vec{J}_d}\right| = \frac{\sigma}{\omega\varepsilon} \rightarrow \vec{J}_c\ \&\ \vec{J}_d$ are out of phase (not 180^0). In time and they are in the same direction in space.

- **Loss tangent/Dissipation factor**

$$\tan\delta = \left|\frac{\vec{J}_c}{\vec{J}_d}\right| = \frac{\sigma}{\omega\varepsilon_0} \quad (\delta \rightarrow \text{loss angle})$$

- **Vector wave equation or vector Helmholtz's equation**
- **Case I- For frequency domain**

For Electric field	$\boxed{\nabla^2\vec{E}_s - \gamma^2\vec{E}_s = 0}$
For magnetic-field	$\boxed{\nabla^2\vec{H}_s - \gamma^2\vec{H}_s = 0}$

- **Case II-For time domain**

Electric wave equation	$\nabla^2\vec{E} = \mu\sigma\frac{d\vec{E}}{dt} + \mu\varepsilon\frac{d^2\vec{E}}{dt^2}$
Magnetic wave equation	$\nabla^2\vec{H} = \mu\sigma\frac{d\vec{H}}{dt} + \mu\varepsilon\frac{d^2\vec{H}}{dt^2}$

- **Field Equation of EM wave in S-domain.**

$$\boxed{\begin{aligned} E_S(z) &= E_o e^{-\alpha z}.e^{j(\omega t - \beta z)a_x} \\ H_S(z) &= H_o e^{-\alpha z}.e^{j(\omega t - \beta z)a_y} \end{aligned}}$$

- **Field equation of EM wave in the time Domain**

$$\boxed{\begin{aligned} E(z,t) &= E_o e^{-\alpha z}\cos(\omega t - \beta z)a_x \\ H(z,t) &= H_o e^{-\alpha z}\cos(\omega t - \beta z)a_y \end{aligned}}$$

Intrinsic Impedance (η)	$\boxed{\eta = \frac{E}{H}\Omega}$, $\eta = \sqrt{\frac{j\omega\mu}{\sigma + j\omega\varepsilon}}$ For free space $\eta_0 = \sqrt{\frac{\mu_0}{\varepsilon_0}} = 120\pi = 377\Omega$
Phase velocity	$\boxed{v_p = \frac{\omega}{\beta} = \frac{C}{\sqrt{\mu_r\varepsilon_r}}\text{m/s}}$
Skin Depth	$\boxed{\delta = \frac{1}{\alpha} = \sqrt{\frac{1}{\pi f\mu\sigma}}\text{meter}}$ $\delta \propto \frac{1}{\sqrt{f}}$
Surface or skin Resistance	$\boxed{R_S = \frac{1}{\sigma\delta} = \sqrt{\frac{\pi f\mu}{\sigma}}\ \Omega/m^2}$

➤ Plane waves in good conductor

$\sigma >> \omega\varepsilon$	$\alpha = \beta = \sqrt{\frac{\omega\mu\sigma}{2}} = \sqrt{\pi f\mu\sigma}$
$v_p = \frac{\omega}{\beta} = \sqrt{\frac{2\omega}{\mu\sigma}}$, $\lambda = \frac{2\pi}{\beta}$	$\eta = \sqrt{\frac{\omega\mu}{\sigma}}\angle 45°$

- **Poynting Theorem-** The net power flowing out volume V is equal to the time rate of decrease in the energy stored within volume V minus the ohmic loss.

$$\boxed{\oint_S(\vec{E}\times\vec{H}).d\vec{S} = -\frac{\partial}{\partial t}\int_V\left[\frac{1}{2}\varepsilon(\vec{E})^2 + \frac{1}{2}\mu(\vec{H})^2\right]dV + \int_V(\sigma\vec{E}^2)dV}$$

Where,
$\oint_S(\vec{E}\times\vec{H})d\vec{S}$ = Total power leaving the volume
$\int_v(\sigma\vec{E}^2)dV$ = Ohmic power dissipation
$-\frac{\partial}{\partial t}\int_v\left[\frac{1}{2}\varepsilon(\vec{E})^2 + \frac{1}{2}\mu(\vec{H})^2\right]dV$ = rate of decrease in energy stored in electric and magnetic field.

- **Poynting vector -** $\boxed{\vec{P} = \vec{E}\times\vec{H}}$ W/m^2

Instantaneous power density	$\vec{P} = \frac{E_0^2}{\eta}\cos^2(\omega t - \beta z)\hat{a}_z$
Average power density in lossless medium	$\vec{P}_{avg} = \frac{1}{2}\frac{E_x^2}{\eta_0}\hat{a}_z = \frac{1}{2}E_xH_y\hat{a}_z$ $= \frac{E_{rms}^2}{\eta}\hat{a}_z = E_{rms}H_{rms}\hat{a}_z$

- **Incidence of EM wave**

Reflection coefficient	$\boxed{\Gamma = \frac{E_r}{E_i} = \frac{\eta_2 - \eta_1}{\eta_2 + \eta_1} = \frac{\sqrt{\varepsilon_1} - \sqrt{\varepsilon_2}}{\sqrt{\varepsilon_1} + \sqrt{\varepsilon_2}}}$
Transmission Coefficient	$\boxed{T = \frac{2\eta_2}{\eta_2 + \eta_1} = \frac{2\sqrt{\varepsilon_1}}{\sqrt{\varepsilon_1} + \sqrt{\varepsilon_2}}\{T = 1 + \Gamma\}}$
Standing Wave Ration (SWR)	$\boxed{S = \frac{1 + \lvert\Gamma\rvert}{1 - \lvert\Gamma\rvert} \text{ or } S = \frac{1+\rho}{1-\rho} \text{ or } S = \frac{V_{max}}{V_{min}}}$
Snell's law for EM waves	$\boxed{\frac{\sin\theta_t}{\sin\theta_i} = \frac{\eta_1}{\eta_2} = \sqrt{\frac{\varepsilon_1}{\varepsilon_2}}}$
Brewster's Angle (θ_B)	$\boxed{\tan\theta_B = \frac{\eta_2}{\eta_1} = \sqrt{\frac{\varepsilon_2}{\varepsilon_1}}}$
Total internal reflection	$\boxed{\theta_c = \sin^{-1}\sqrt{\frac{\varepsilon_2}{\varepsilon_1}}}$ θ_c = Critical angle

- **Polarization (P)-** Polarization is electric field orientation of electromagnetic wave at a fixed position in space with respect to time.

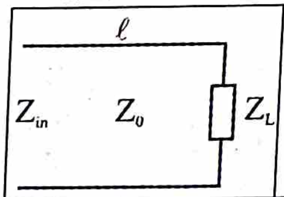
Electromagnetic field in x and y direction only $E(z,t) = E_{x0}\cos(\omega t - \beta z + \phi_x)\hat{a}_x + E_{y0}\cos(\omega t - \beta z + \phi_y)\hat{a}_y$	
Electromagnetic wave propagate in z-direction and electric field direction in x only $E(z,t) = E_{x_0}\cos(\omega t - \beta z + \phi_x)\hat{a}_x$	linear horizontal polarization
Electromagnetic wave propagate z, electric field in y-direction only $E(z,t) = E_{y0}\cos(\omega t - \beta z + \phi_y)\hat{a}_y$	linear vertical polarization

$E_{x0} = E_{y0} = E_0$ and $\phi = \pm 90^0$ $E_x = E_{x0} \cos \omega t$ $E_y = E_{y0} \cos(\omega t + \phi) = \pm E_0 \sin \omega t$	circular polarization
$\phi = \pm 90,\ E_{x0} \neq E_{y0}$ $E_x = E_{x0} \cos \omega t$ $E_y = E_{y0} \cos(\omega t + \phi) = \pm E_{y0} \sin \omega t$	Elliptical polarization

❑ Transmission line

Characteristic impedance	$\boxed{Z_0 = \frac{V^+}{I^+} = \sqrt{\frac{R + j\omega L}{G + j\omega C}}\ \Omega}$
Propagation constant	$\gamma = \alpha + j\beta$ $= \sqrt{(R + j\omega L)(G + j\omega C)}\ m^{-1}$ Where, α= Attenuation constant, β = Phase shift constant
$\left[\begin{array}{l}\gamma = \text{Propagation constant of medium} \\ \gamma = \alpha + j\beta \text{ and } \gamma^2 = j\omega\mu(\sigma + j\omega\varepsilon)\end{array}\right]$	
$\text{Attenuation constant}(\alpha) = \omega\sqrt{\frac{\mu\varepsilon}{2}\left[\sqrt{1 + \left(\frac{\sigma}{\omega\varepsilon}\right)^2} - 1\right]}$	
$\text{Phase constant } (\beta) = \omega\sqrt{\frac{\mu\varepsilon}{2}\left[\sqrt{1 + \left(\frac{\sigma}{\omega\varepsilon}\right)^2} + 1\right]}$	
Lossless transmission line	$\boxed{R = G = 0,\ \ Z_0 = R_0 = \sqrt{\frac{L}{C}}}$ $v = \frac{\omega}{\beta} = \frac{1}{\sqrt{LC}} = f.\lambda$
Distortion less transmission line	$\boxed{\frac{R}{L} = \frac{G}{C},\ \ \alpha = \sqrt{RC} \text{ and } \beta = \omega\sqrt{LC}}$ $\boxed{Z_0 = \sqrt{\frac{R}{G}} = \sqrt{\frac{L}{C}}}$

- **Behaviour of transmission line due to variation in load**

	$Z_{in} = Z_0\left(\frac{Z_L + jZ_0 \tan\beta\ell}{Z_0 + jZ_L \tan\beta\ell}\right)$
For short circuit line $(Z_L = 0)$	$Z_{in} = Z_{sc} = jZ_0 \tan\beta\ell$ Quarter wave line$(\lambda/4)$, $Z_{in} = jZ_0 \tan\frac{2\pi}{\lambda} \times \frac{\lambda}{4} = \infty$
For open circuit line $(Z_L = \infty)$	$Z_{in} = Z_{oc} = -jZ_0 \cot\beta\ell$ Quarter wave line$(\ell = \lambda/4)$ $Z_{in} = Z_{oc} = -jZ_0 \cot\frac{2\pi}{\lambda} \times \frac{\lambda}{4}$ $Z_{in} = 0$
For matching line $(Z_L = Z_0)$	$(Z_{in} = Z_0)$
$Z_{in} = \frac{Z_0^2}{Z_L},\ Z_0 = \sqrt{Z_{in} Z_L}$ Z_{in} = input impedance, Z_L= Load impedance	

- **Voltage reflection coefficient-** Ratio of reflected voltage wave to that of the incident wave.

$$\boxed{\Gamma_L = \frac{Z_L - Z_0}{Z_L + Z_0}}$$

- **Standing wave ratio-** Ratio of maximum voltage of standing wave to the minimum voltage of standing wave-

$$\boxed{S = \frac{V_{max}}{V_{min}} = \frac{1 + |\Gamma_L|}{1 - |\Gamma_L|}}$$

- **Current reflection coefficient-** The current reflection coefficient at any point on the line is the negative of the voltage reflection coefficient at that point i.e. $-\Gamma_L$.

☞ **Remember point**

Short circuited line (Z_L= 0)	$\Gamma_L = -1, \quad S = 0$
Open circuit line $(Z_L = \infty)$	$\Gamma_L = 1, \ S = \infty$
Matched line (Z_{in} = Z_0)	$\Gamma_L = 0, \ S = 1$

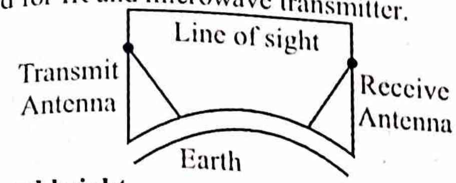
- Characteristics Impedance $\boxed{Z_0 = \sqrt{Z_{sc} Z_{oc}}}$

❑ Wave propagation of antenna -

Ground wave propagation	Sky wave propagation	Space wave propagation
It exists in the frequency range of 30 kHz to 3 MHz	Exists in the range of 3 MHz to 30 MHz	Used for frequencies above 30 MHz
Ground waves are vertically polarized	Vertical polarized	Horizontally polarized
Used for radio broadcasting	Used for radio broadcasting	Used for TV and FM broad casting
Power loss takes place due to absorption by ground and due to tilting of waves	Power loss due to absorption of energy by the layers of ionosphere	Power loss due to the power absorption and scattering by tall and massive objects
It also called surface wave	It also called ionospheric wave propagation	It also called ionospheric propagation

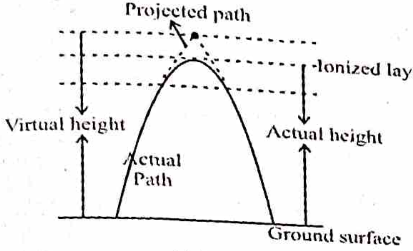
- **Line of sight propagation (LOS) -**

➢ Used for IR and microwave transmitter.


Line of sight
Transmit Antenna
Receive Antenna
Earth

- **Virtual height -**

➢ The incident wave reflected from which point the point or height greater than that height is known as virtual height.


Projected path
Ionized layer
Virtual height
Actual height
Actual Path
Ground surface

- **Critical frequency (f_c) -**

➢ Highest frequency that will returned down to the earth.

➢ Critical frequency range for f2 layer is (5 MHz to 12 MHz).

- **Fading** - Decreases in the quality of the signal is known as fading.

➢ It happens due to multipath.

- **Skip distance -**

➢ Measureable distance on the surface of earth from transmitter to receiver.

- **Maximum Usable frequency (MUF)** - The highest frequency delivered by the transmitter.

$$\text{MUF} = \frac{\text{Critical frequency}}{\cos\theta} = f_c \sec\theta$$

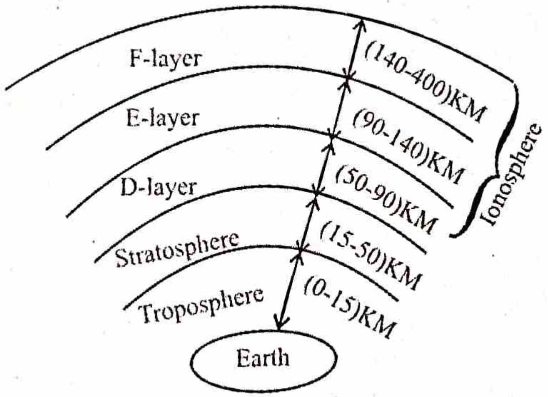
- **Optimum Working frequency (OWF) -**

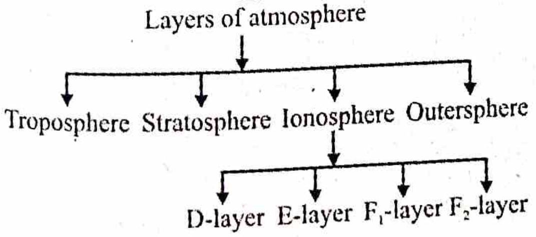
➢ Frequency which is being used mostly for a particular transmission.

- **Inter Symbol Inter frequency (ISI) -**

➢ The signals by multipath overlap each other and cancel other signal is known as ISI.

❑ Layer of atmosphere -


F-layer
E-layer
D-layer
Stratosphere
Troposphere
Earth
(140-400)KM
(90-140)KM
(50-90)KM
(15-50)KM
(0-15)KM
Ionosphere


Layers of atmosphere
Troposphere
Stratosphere
Ionosphere
Outersphere
D-layer
E-layer
F₁-layer
F₂-layer

☞ **Remember point**

➢ During the day, D,E,F_1,F_2 layer are present in Ionosphere.

➢ During Night only E and F layer are present in Ionosphere.

❑ Antenna

➢ Antenna is an electrical device (conductor) which converts electrical energy into electromagnetic waves and vice-versa.

➢ An antenna consist of a transmitter and receiver, used for sending and receiving electromagnetic waves.

➢ Radiate any signal from transmitter to space.

➢ Antenna is used to impedance matching between transmission line and free space.

Antenna	Current distribution
Resonant	Standing wave pattern
Non-resonant	Traveling wave pattern

❑ Basic parameter of Antenna-

- **Wave length-**

➢ Wave length is the distance between two consecutive maximas or minimas.

$$\lambda = \frac{c}{f}$$

- **Impedance matching-**

➢ Power radiated by Antenna is only radiated effectively, if antenna's impedance is perfectly matched with free space impedance.

- **VSWR (Voltage standing wave ratio)-**

➢ Higher value of impedance mismatch causes higher value of SWR.

➢ SWR stands for standing wave ratio.

- **Band width-**

➢ The range of frequency for which signal gain is non-zero.

➢ $BW = F_H - F_L$

- **Radiation Intensity-**

➢ Power per unit solid angle is called radiation intensity.

➢ $U = r^2.P_{radial}$

Where r = Radial distance.

P_{radial} = Radiated power.

- **Directivity (D)-**

➢ Ratio of maximum radiation intensity of subject antenna to an reference or isotropic antenna.

➢ Ability of an antenna to radiate in a particular direction.

➢ $D = G_d(\theta,\phi)_{max} = \dfrac{4\pi U(\theta,\phi)_{max}}{P_{rad}}$

- **Aperture efficiency-**

➢ $\text{Aperture efficiency} = \dfrac{A_{effective}}{A_{Physical}}$

- **Antenna efficiency-**

➢ $\eta_e = \dfrac{P_{radiated}}{P_{Input}}$

- **Effective length-**

➢ $\ell = \frac{V_A}{E}$ Where,

V_A = Induced voltage.
E = Electrical field.

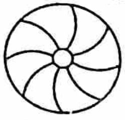
- **Isotropic Antenna or Omni directional antenna-**

➢ Standard reference antenna radiating equally in all direction.

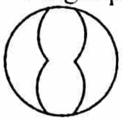
➢ Practically this is not possible to radiate all the power or energy equally in all direction.

➢ In 3D, It is viewed as doughnut shape.

➢ In 2D, It is viewed as figure of eight pattern.



For 3D



For 2D

- **Beam Area-**

➢ Maximum power radiation direction comes at which angle from antenna is known as solid angle.

➢ Solid beam angle is known as Beam area.

$dA = r^2.d_{\Omega A}$ where $d_{\Omega A}$ = Beam area
r = radial distance

- **Beam width-**

➢ The area where most of the power is radiated.

➢ Beam width is understood by two categories.

- **HPBW (Half Power Beam Width)-**

$HPBW = K.\frac{\lambda}{D}$ Where K = 70(constant)

λ = wave length,
D = diameter

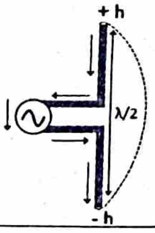
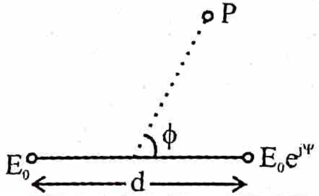
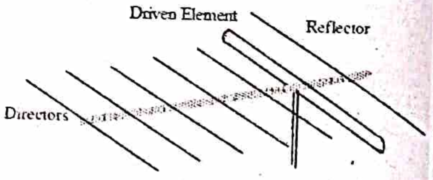
- **FNBW (First Null Beam Width)-**

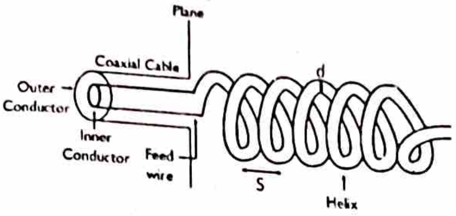
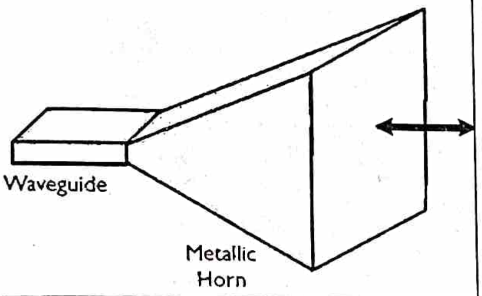
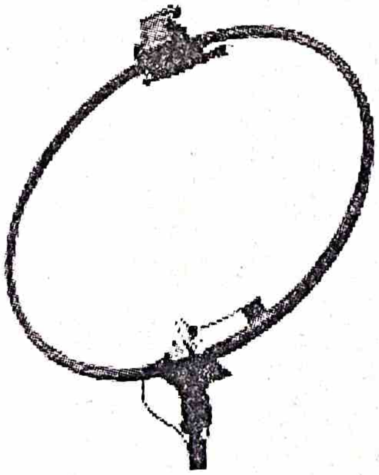
$$FNBW = 2(HPBW)$$
$$= 2K.\frac{\lambda}{D}$$

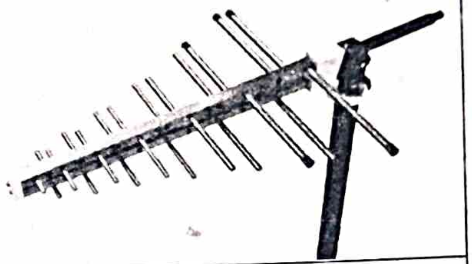
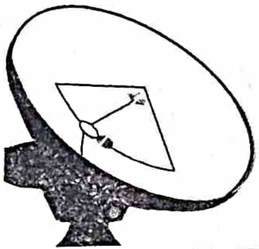
- **Effective area-**

➢ $A_{eff} = \frac{\lambda^2}{4\pi}.G_m$

❑ Types of Antenna-

Ungrounded Antenna	An antenna which is kept above the surface of ground without touching the ground or without any electrical connection with ground.
Half wave dipole antenna	Antenna frequency operating over half of the wave length. Total wave length = $\lambda/2$. ➢ Operating frequency = 3KHz to 300 MHz. ➢ Directivity = 2.15 dB. ➢ A $\lambda/2$ antenna is also known as hertz antenna. 
Half wave folded dipole antenna	➢ Antenna length = $\lambda/2$. ➢ Impedance = 300Ω. ➢ Mainly used for where antenna array are used. ➢ Best example = Yagi Uda Antenna.
Antenna Array	➢ It is a set of two or more antenna which are combined to improve performance over single antenna. ➢ Improve directivity. ➢ Increase SNR. ➢ Very less minor lobes. ➢ Gain increased. ➢ Array factor = $\left\lvert \frac{\sin N(\psi/2)}{\sin(\psi/2)} \right\rvert$ $\psi = \beta d \cos\phi + \alpha$, $\beta = \frac{2\pi}{\lambda}$ 
Yagi Uda Antenna-	➢ Most widely used Antenna. ➢ Used for TV-reception. ➢ Famous for high directivity and gain. ➢ Higher value of gain (7-8) dB. ➢ Known as super directive antenna. ➢ Very less amount of power is loss. ➢ Directivity increase by adding more directors. 
Rhombic antenna-	➢ Input impedance = (650 to 700)Ω. ➢ Terminating resistance = 800Ω. ➢ Directivity = 20° to 90°.
Helical Antenna	➢ Based on faraday effect. ➢ Circular polarized antenna. ➢ Used of VHF and UHF communication and radio telemetry. ➢ Used for satellite and probe communication. ➢ $HPBW = \frac{52}{C}\sqrt{\frac{\lambda^3}{NS}}$ ➢ $BWFN = \frac{115}{C}\sqrt{\frac{\lambda^3}{NS}}$

	where, N = no. of turns, S = spacing between the turns.  Ground Plane Coaxial Cable Outer Conductor d Inner Conductor Feed wire S Helix
Horn antenna	➢ Simple in construction. ➢ Highly directive. ➢ High gain. ➢ Very low noise antenna. ➢ Used in satellite tracking. ➢ HPBW in H-plane $\theta_H^\circ = \frac{67^\circ\lambda}{a_H}$ ➢ HPBW in E - plane. $\theta_E^\circ = \frac{56^\circ\lambda}{a_E}$ ➢ Directivity(D) = $\frac{7.5A_P}{\lambda^2}$, $A_P = a_E \times a_H$ 
Loop antenna	➢ Used in direction finding. ➢ It is a single turn coil carrying RF current. ➢ Pattern of radiation is doughnut shape. ➢ Small dimensions. 

Log-periodic antenna	➢ Large in physical appearance. ➢ Directive gain is moderate. ➢ Radiation pattern may be unidirectional or bi-directional. ➢ Used for television reception. ➢ Bandwidth is very high. 
Parabolic reflector	➢ It consist of a parabolic antenna as a reflector and a microwave antenna at the feed point. ➢ Used in microwave frequencies. ➢ $G = \frac{4\pi A}{\lambda^2} e_A$ Where A = Area of antenna aperture. ad = diameter of the parabolic reflector. e_A = Aperture efficiency. 
Broad side array	➢ Broad side array is an array which gives a radiation pattern whose main beam is perpendicular to the axis of the array. ➢ A number of dipoles of equal size are used. ➢ The elements are spaced equally. ➢ All the dipoles are fed in the same phase. ➢The null-to-null beamwidth of broadside array.
End fire array	➢ If maximum radiation occurs at θ=0 or π then this is called end fire array for maximum radiation. ➢ A number of dipoles or elements of equal size are used. ➢ The element are equally spaced. ➢ The elements are fed with different phases.

MATERIAL SCIENCE

Crystal Structure :

Crystal - When atoms, molecules and ions are arranged in a highly ordered microscopic structures then a crystal or crystalline solid is formed. Crystals combining together to form crystal lattice that extends in all directions.

Examples – Diamonds, snow flakes, table salt etc.

Crystals are arranged in regular and ordered manner in three dimensional pattern.

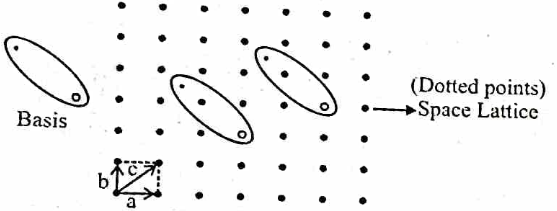
- **There are three types of crystals –**
  - i. Crystalline solids
  - ii. Non Crystalline
  - iii. Quasi Crystalline

Space lattice - A space lattice is defined as an infinite array of points in three dimensional space in which each point is identically located with respect to each other.

- **A three dimensional Space lattice may have-**

➢ Cubic array (a = b = c)

➢ Non cubic array



Crystal Structure

Basis or Motif - The atoms, molecule, ion or radical called the repeating unit assembly when located at each Lattice point is called basis or motif.

➢ Lattice + Basis → Crystal structure

Unit Cell - It is the minimum area cell in two dimension and minimum volume cell in three dimension which may generate whole cyrstalline solid.

The volume of unit cell $\boxed{V = \vec{a}\cdot\vec{b}\cdot\vec{c}}$

Where $\vec{a}, \vec{b}\ \&\ \vec{c}$ are Lattice Parameters along x, y and z directions.

In three dimensions cells counting of atoms-

➢ Vertex atom → $\frac{1}{8}$ atom per cell

➢ Edge atom → $\frac{1}{4}$ atom per cell

➢ Face atom → $\frac{1}{2}$ atom per cell

➢ Body unique → 1 atom per cell

Atomic radius- Atomic radius is half of the distance between nearest neighbours (atoms) in a crystal of pure element.

Atomic packing factor -

$$\boxed{\text{APF} = \frac{\text{Volume of the atoms}}{\text{Volume of the unit cell}}}$$

Comparison of unit cell properties of cubic crystal structures

Properties	Diamond cube (DC)	Simple cube (SC)	Body centred cube (BCC)	Face centred cube (FCC)
Volume of unit cell	a^3	a^3	a^3	a^3
Number of atoms per unit cell	8	1	2	4
Number of atoms per unit volume	$\frac{8}{a^3}$	$\frac{1}{a^3}$	$\frac{2}{a^3}$	$\frac{4}{a^3}$
Number of nearest neighbours (coordination number)	4	6	8	12
Nearest neighbour distance (2r)	$\frac{a\sqrt{3}}{4}$	a	$\frac{a\sqrt{3}}{2}$	$\frac{a\sqrt{2}}{2}$
Atomic radius	$\frac{a\sqrt{3}}{8}$	$\frac{a}{2}$	$\frac{a\sqrt{3}}{4}$	$\frac{a\sqrt{2}}{4}$
Atomic packing factor	$\frac{\pi\sqrt{3}}{16} = 0.34$	$\frac{\pi}{6} = 0.52$	$\frac{\sqrt{3}\pi}{8} = 0.68$	$\frac{\sqrt{2}\pi}{6} = 0.74$
Examples	Ge, Si and C	Polonium	Na, Li and Cr	Al, Cu, Ag and Pb

- **Miller Indices** - Miller indices are used to represent orientation of a plane. Three indices are used for x, y, z direction.

$$\boxed{\text{Indices} = \frac{1}{\text{Intercept in that direction}}}$$

- Bragg's law and x-ray diffraction- $\boxed{n\lambda = 2d\sin\theta}$

- **Atomic Bonding** - Forces between atoms are called inter-atomic forces may be attractive or repulsive forces.

i. Ionic Bonding ii. Covalent Bonding
iii. Metallic Bonding

Magnetic Materials

Materials that can be magnetized is called magnetic materials. Net magnetic field produced by an electron at nucleus is zero.

Remember point

Magnetization means alignment of dipoles in the direction of applied magnetic field.

- **Magnetic Dipole** - Two unlike magnetic poles of equal pole strength at a very small distance is known as magnetic dipoles.

Example : A small bar magnet, magnetic needle, a current carrying loop etc.

- **Magnetic Laws** -Magnetic Laws are following –

- **Biot-savart Law**– $\boxed{dB = \frac{\mu_0}{4\pi}\frac{Id\ell\sin\theta}{r^2}}$

B = Magnetic field, r = Distance , $d\ell$ = Differential length

- **Ampere's circuital Law : -**

Ampere law is analogous to gauss's law in electrostatics.

$\boxed{H = \frac{I_{enc}}{2\pi r}}$ also $\boxed{\oint_C \vec{H}\cdot\vec{dl} = I_{enc}}$

- **Magnetic flux density :-**

$\boxed{B = \frac{\phi}{A} = \mu H}$ (Wb/m^2 or Tesla)

- **Magnetic susceptibility(χ_m)-** Magnetic susceptibility is the degree of magnetization of a material in response to an applied magnetic field.

$\boxed{\chi_m = \frac{M}{H}}$ $\begin{matrix}\to \text{Magnetization} \\ \to \text{Magnetic field intensity}\end{matrix}$

It is unitless proportionality constant.

- **Magnetic Moment-** $\boxed{m = I \times A}$ in Amp-m^2

m -Magnetic moment, I - Current, A → Area

Magnetization(M)= $\frac{m_{net}}{V}$ $\begin{matrix}\to \text{Net magnetic moment} \\ \to \text{Volume}\end{matrix}$

$$\therefore M = \frac{Am^2}{m^3} = A/m$$

- **Magnetic Intensity -**

$$B = B_0 + B_m = \mu_0(H + M)$$

$$B = \mu_0 H + \mu_0 M = \mu_0 H + \mu_0 \chi_m H$$

$$= \mu_0 H(1 + \chi_m) = \mu_0\mu_r H \qquad [\because \mu_r = 1 + \chi_m]$$

- **Bohr Magneton-** Smallest unit of magnetic moment is Bohr Magneton.

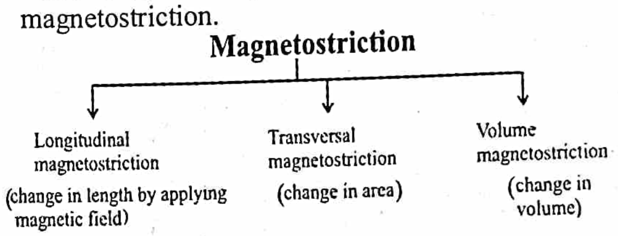
$\boxed{P_B = \frac{neh}{4\pi m}}$ for n = 1, $P_B = 9.27 \times 10^{-24}$ Amp-m^2 or J/T

- **Magnetic Anisotropy-** Different magnetic properties exhibited by ferromagnetic materials in different directions is known as magnetic anisotropy.

- **Causes of magnetic anisotropy :-**

- **Cold working** – when material is shaped without increasing temperature.
- **Annealing :-** Heat treatment of a material
- **Quenching :-** Immediate cooling after heating.

- **Magnetostriction :-** Change in dimension of a material when magnetic field is applied is called magnetostriction.


Magnetostriction
Longitudinal magnetostriction
(change in length by applying magnetic field)
Transversal magnetostriction
(change in area)
Volume magnetostriction
(change in volume)

Remember point

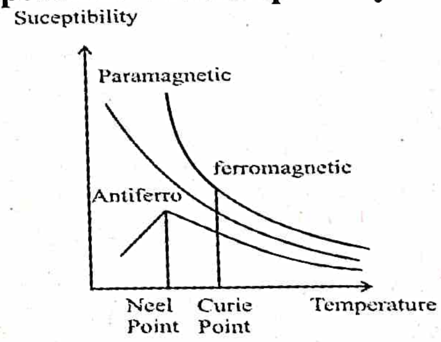
- Converse of magnetostriction is called "Villari effect."

- **Curie Temperature-** The temperature at which a ferromagnetic material becomes paramagnetic in nature. A magnetic material completely loses its magnetic property at curie temperature.

According to curie's law-

i.e. $\boxed{\chi_m = \frac{C}{T}}$ Where, C → Curie's constant

- **Temperature Vs Susceptibility :-**



- **Paramagnetic** – Curie's law $\boxed{\chi_m = \frac{C}{T}}$

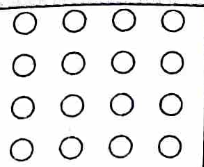
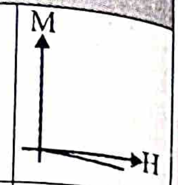
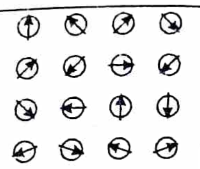
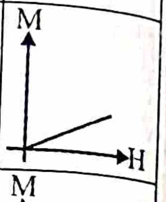
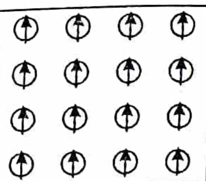
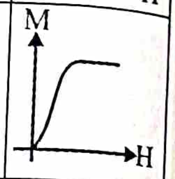
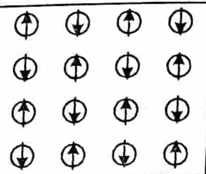
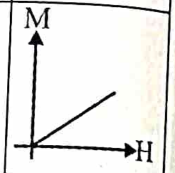
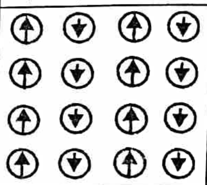
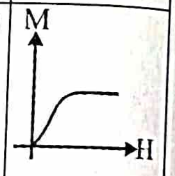
- **Ferromagnetic** – Curie- weiss law $\boxed{\chi_m = \frac{C}{T - \theta}}$

θ- Curie's temperature, $T > \theta$ (ferro → para)

- **Anti ferromagnetic** – Curie – weiss law

$\boxed{\chi_m = \frac{C}{T + \theta_n}}$ $T > \theta_n$ (Neel's Temp)

Summary of magnetic materials -

Type	Example	Atomic/Magnetic Behaviour		
Diamagnetism	Inert gases, many metals - Au, Cu, Hg, non-metallic elements - B, Si, P, S, many ions - Na^+, Cl & their salts, diatomic molecules - H_2, N_2, H_2O, most organic compounds	Atoms have no magnetic moment. Susceptibility is small & negative.		
Paramagnetism	Some metals - Al, some diatomic gases - O_2, NO, ions of transition metals and rare earth metals, and their salts, rare earth oxides.	Atoms have randomly oriented magnetic moments. Susceptibility is small & positive.		
Ferromagnetism	Transition metals Fe, CrO_2, Co, Ni, alloys of ferromagnetic elements, some alloys of Mn - MnBi, Cu_2MnAl.	Atoms have parallel aligned magnetic moments. Susceptibility is large (below T_C)		
Antiferromagnetism	Transition metals Mn, Cr & many of their compound - MnO, CO, NiO, Cr_2O_3, MnS, MnSe, CuC_2.	Atoms have antiparallel aligned magnetic moments. Susceptibility is small & positive,		
Ferrimagnetism	(Fe_3O_4-magnetite), (Fe_2O_3-maghemite), mixed oxides of iron and other elements such as Sr ferrite.	Atoms have mixed parallel and anti-parallel aligned magnetic moments. Susceptibility is large (below T_c)		

Calculation of magnetization in magnetic material

- **Magnetization of Paramagnetic materials**

➢ $M = \mu_m N_p - \mu_m N_a$ (Where, μ_m –Dipole moment)

$= (N_p - N_a)\,\mu_m = 2\mu_m N \tanh\alpha$

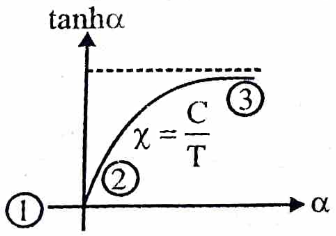
➢ $N_p = N_0 \exp\left[\dfrac{-E_P}{K_B T}\right]$, $N = N_p + N_a$

➢ $N_a = N_0 \exp\left[\dfrac{-E_a}{K_B T}\right]$

Where, N_a – Anti parallel dipole

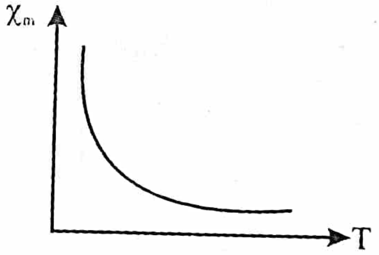
N_p – Parallel dipole, E_p – Energy of equal dipole

E_a – Energy of unequal dipole



➢ $\chi_m = \dfrac{M}{H} = \dfrac{N\mu_0\mu_m^2}{K_B T}$

$\therefore C = \dfrac{N\mu_0\mu_m^2}{K_B}$,



Important Terms Related to magnetism –

➢ **Air gap :-** The distance between north and south poles of magnetic circuit.

➢ **Coercive force :-** The magnetic field required to reduce the residual magnetism to zero value.

➢ **Residual magnetism :-** Remaining magnetisation in the magnet after magnetic field intensity is zero.

➢ **Gauss** – The unit of magnetic induction or magnetic flux density used to measure the magnetic field density (magnetic flux/cm^2)

➢ **MGO** – Mega Gauss Oersted

➢ **Oersted -** The unit of magnetic intensity in the CGS system that describes magnetic force.

➢ **Retentivity :-** The material's ability to retain the magnetization when magnetic field is removed after saturation.

Types of magnetic materials :-

- **Soft magnetic materials :-** These are used in transformer, electric machines and magnetic memory.

Ex. Iron, Iron-silicon alloys, Nickel-iron alloys.

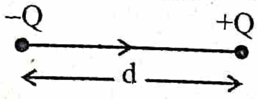
- **Hard magnetic materials :-** These are also called permanent magnetic materials.
  Ex- Alnico, Chromium steel, Tungsten steel, Carbon steel etc.

☐ **Dielectric materials-** Dielectric materials are basically insulators contains no free electrons. These can be easily polarized when electric field is applied. They have ability to store energy in form of electric field.

Dielectric Terms

- **Relative permittivity or dielectric constant (ε_r) -** The dielectric constant is a measure of the amount of electric potential energy. This energy is known as electrostatic energy. $\boxed{\varepsilon = \varepsilon_r\varepsilon_0}$
  Where, ε_r– Relative permittivity = 1 (For air & vacuum)
  ε_0 = Permittivity of vacuum = 8.854×10^{-12} F/m
- **Permittivity –** The permittivity relates to a material's ability to transmit (or "permit") an electric field.
- **Dipole moment -** A dipole moment is the product of the charge and the distance between them.

$\boxed{\vec{P} = Q\vec{d}}$



It is measured in Debye units (D).
Dipole moment 1D = 3.33×10^{-30} Coulomb-meter

- **Polarization-** The total effect of an external electric field on any dielectric material is called polarization of dielectric.
  The electric dipole moment per unit volume is called polarization or polarization density ($\vec{P}$).

$$\boxed{\begin{aligned}&\vec{P} = N\vec{p}\ (\text{Coulomb/m}^2)\quad \vec{P} \propto \vec{E}\\&\vec{P} = \chi_e\varepsilon_0\vec{E},\quad \vec{D} = \varepsilon_0\vec{E}+\vec{P} = \varepsilon_0(1+\chi_e)\vec{E}\end{aligned}}$$

$\vec{p}$ - Polarization of each molecule

N - No. of molecules (Atoms) $\left\{N = \dfrac{n}{\text{Volume}}\right\}$

$$\boxed{\text{Electrical suceptibility } (\chi_e) = \frac{\text{Bound charge density}}{\text{Free charge density}}}$$

- **Polarizability –** $\boxed{\alpha = \dfrac{P}{E}\left(\text{Farad} - \text{m}^2\right)}$

$$\boxed{\alpha = \frac{\varepsilon_0\chi_e}{N} = \frac{\varepsilon_0(\varepsilon_r - 1)}{N}}$$

E = Electric field, P = Dipole moment

- **Electric flux density**

> $\vec{D} = \varepsilon\vec{E}$ ...... for isotropic materials
>
> Electric flux density when electric field is applied
>
> $\vec{D} = \varepsilon_0\vec{E} + \vec{P}$

> The stored energy per unit volume in dielectric medium
>
> $E = \dfrac{1}{2}\vec{P}\vec{E}$ {P - Dipole moment}

Mechanism of Polarization

- **Electronic Polarization-** The polarization occurred due to displacement of positive charge and negative charge in dielectric material is called electronic polarization.
  $\boxed{P_e = N\alpha_e E}$
  Where, $\alpha_e = 4\pi\varepsilon_0 R^3$ {R - Radius of atom}
  $\boxed{\alpha_e = \dfrac{\varepsilon_0(\varepsilon_r - 1)}{N}}$, $\boxed{\varepsilon_r = 1 + 4\pi NR^3}$......for rare gases
- **Ionic Polarization-** Ionic polarization occurs only in those dielectric material in which atoms contain ionic bonds.

➢ When external electric field is applied then distance between charges increases.

➢ $\boxed{P_i = N\alpha_i E}$ Ionic polarization
Where α_i → Ionic polarizability
$\boxed{\alpha_i = \dfrac{1}{10} \times \alpha_e}$

➢ Ionic polarization is temperature independent.

- **Oriental polarization-** Polar dielectric exhibit orientational polarization even in the absence of electric field. That is called oriented polarization.
  $\boxed{P_0 = \dfrac{NP_p^2}{3kT}E}$, $\boxed{P_0 \propto \dfrac{1}{T}}$.

As temp ↑ → randomness ↑→ net dipole moment↓

Where, N - No. of permanent dipoles
P_p - Permanent dipole moment,
E- External electric field
k -Boltzmann constant
T –Temperature, P_0 - Oriental polarization

- **Orientational polarizability-**
  $\boxed{\alpha_0 = \dfrac{P_p^2}{3kT}}$ .... Curie's law
- **Total polarization of a polygamic gas-**

$$\boxed{\begin{aligned}&P = P_e + P_i + P_0 = N\alpha_T E\\&P = N\left(\alpha_e + \alpha_i + \frac{P_p^2}{3kT}\right)E\\&\therefore\ \varepsilon_0\chi_e = N(\alpha_e + \alpha_i) + \frac{NP_p^2}{3kT}\end{aligned}}$$

☞ Remember point

Orientational polarization depends on temperature and frequency. It is applied only to polar dielectrics.

- **Interfacial polarization or space charge polarization :-**

  Total polarization

  $\boxed{P = P_e+P_i+P_0+P_s}$ {for multiphase material)

  Where, P_s = Interfacial Polarization

➢ For single phase material, P_s becomes zero.

- **Internal field in solids and Liquids**

  $\boxed{E_{int} = E_0+E_p+E_s+E_d}$

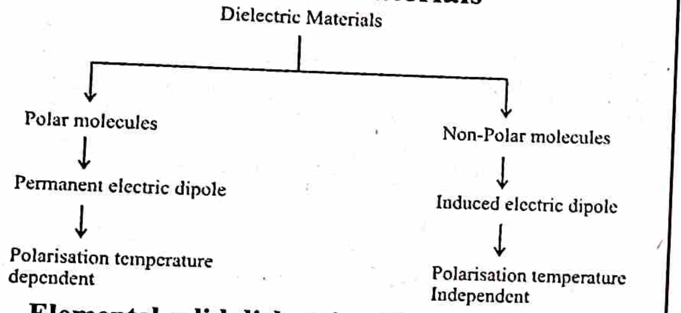
  $E_0 \rightarrow$ Field produced by charged for external to dielectric specimen.

  $E_0 = \frac{D}{\varepsilon_0}$, $E_P \rightarrow$ Depolarization field

  $E_p = \frac{-P}{\varepsilon_0}$ and $E_s = \frac{\gamma P}{\varepsilon_0}$, For cubic structure $\gamma = \frac{1}{3}$

  Internal field $\boxed{E_{int} = E + \frac{P}{3\varepsilon_0}}$ (Lorentz field)

Types of Dielectric Materials


Dielectric Materials
Polar molecules
Permanent electric dipole
Polarisation temperature dependent
Non-Polar molecules
Induced electric dipole
Polarisation temperature Independent

- **Elemental solid dielectrics-** The materials which do not contain ions or permanent dipoles and consist of single type of atoms.

$$\boxed{\varepsilon_r = (\chi_e + 1) = \frac{1-(1-\gamma)\frac{N\alpha_e}{\varepsilon_0}}{1-\frac{\gamma N\alpha_e}{\varepsilon_0}}}$$

- **Ionic Non-polar solid dielectrics-** These solids contain more than one type of atoms, but no permanent dipoles.
- **Polar Solid :-**

  In these solids molecules possess permanent dipole moments.

- **Clausius – Mosotti Relation -** $\boxed{\frac{N\alpha_e}{3\varepsilon_0} = \frac{\varepsilon_r - 1}{\varepsilon_r + 2}}$
- **Maxwell's relation for index of refraction :-**

  $\boxed{\varepsilon_{re} = n^2}$ (Consider $\mu = \mu_0$)

  Where, ε_{re}- dielectric constant at optical frequencies

  n -Refractive index

- **In Clausius-mosotti relations for gases at low pressure-**

  $\varepsilon_r = 1$ So, $\boxed{\frac{N\alpha_e}{\varepsilon_0} = \varepsilon_r - 1 = \chi_e}$

- **Debye's generalization of clausius-mosotti relation**

  Polarizability per kilogram molecule

  $$\boxed{\pi = \frac{N_A\alpha}{3\varepsilon_0} = \frac{\varepsilon_r - 1}{\varepsilon_r + 2}\cdot\frac{M}{\rho}}$$

  Where, π - Molar polarizability

  M-Molecular weight of material, ρ - Density, kg/m^3

- **Maxwell's Relation for optical frequencies or lorentz-lorentz equation –**

  $$\boxed{\pi = \frac{N_A\alpha}{3\varepsilon_0} = \frac{n^2 - 1}{n^2 + 2}\cdot\frac{M}{\rho}}$$

  Lorentz-lorentz equation will apply only for the case $\alpha = \alpha_e$

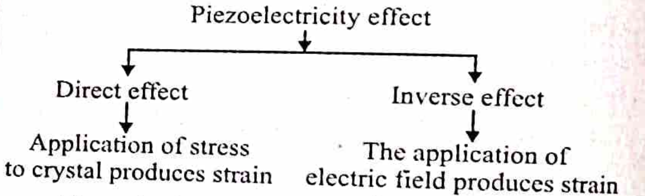
- **Condition for spontaneous polarization** $\frac{N\alpha\gamma}{\varepsilon_0} = 1$

Types of dielectric material in the presence of electric field

- **Piezoelectric material-** Piezoelectric materials or piezoelectrics are the materials that can produce electric energy upon application of mechanical stress.

  Examples- $BaTiO_3$ Crystal, Quartz Crystal, Rochelle salt.

- **Piezoelectricity-** It has two effects-


Piezoelectricity effect
Direct effect
Application of stress to crystal produces strain
Inverse effect
The application of electric field produces strain

  Above both effects are linear, such materials obey the following equations –

  $\boxed{T = cS,\ S = sT,\ P = dT}$

  Where, $T \rightarrow$ Stress, $S \rightarrow$ Strain

  c - Elastic stiffness constant, $s \rightarrow \frac{1}{c}$

  $d \rightarrow$ Piezoelectric strain constant

  Dielectric displacement $\boxed{D = \varepsilon E + dT}$

  Inverse effect can be given as $\boxed{S = sT + dE}$

- **Ferroelectric material -** Ferroelectric materials are those dielectric materials in which permanent polarization remains even after removing the applied electric field.

  Example- Barium Titanate, Sodium nitrite, KDP, Rochelle salt

☞ Remember point

i. By applying external field, direction of polarization can be reversed.

ii. Curie- weiss law is used for ferroelectric material.

- **Pyroelectric material-** Pyroelectric materials are defined as such materials in which spontaneous polarization in the absence of external electric field and changes its polarization on heating.

$\boxed{\Delta P = \lambda \Delta T}$.

Where, ΔP = Change in polarization

λ = Pyroelectric constant

ΔT = Change in temperature

Example- Tourmaline and polyvinylidene fluoride

- **Anti-ferroelectric material**

Dipole moments are aligned antiparallel in these materials. Hence spontaneous polarisation is zero.

Example- ADP, Sodium niobate, Lead zirconate,.

Dielectric breakdown in gases

- **Average velocity of the charge carrier in a gas**

$\boxed{V = \mu E}$

Where, μ - Charge carrier mobility

E- Applied electric field.

- **Secondary ionization coefficient**

$$\boxed{n = \frac{n_0 e^{\alpha d}}{1-\gamma\left(e^{\alpha d}-1\right)}}$$

Where, n- Total no. of electrons

n_0- No. of primary photoelectrons per second

d - Distance between anode and cathode

γ-Townsend's second ionization coefficient

- **Condition of Ionization**

$\boxed{E.\lambda = V_i}$

Where V_i - Ionization potential

λ- Mean free path

Electron ionization coefficient (Town send breakdown process)

$$\boxed{\alpha = \frac{1}{\lambda} e^{-(V_i/E\lambda)}}$$

Where,α = Townsend's first ionization coefficient

$\lambda \propto \frac{1}{\text{Pressure}}$ .... at constant temperature

$n_d = n_0 e^{\alpha d}$

Where, n_d = Number of electrons striking the anode per second

- **Townsend criterion for spark breakdown-**

$$\boxed{\gamma\left(e^{\alpha d}-1\right) = 1}$$

Dielectric breakdown in liquids

- **Colloidal theory-**

$$\boxed{\frac{\varepsilon - \varepsilon'}{\varepsilon + 2\varepsilon'} \cdot r^3 E^3 \geq \frac{kT}{4}}$$

Where, r - Insulating particle radius

ε -Permittivity of insulator

ε'- Permittivity of oil

E - Field strength

k - Boltzmann's Constant

T - Absolute temperature

- **Bubble theory-**

$$\boxed{E_i = \frac{3\varepsilon E_0}{2\varepsilon + 1}}$$

Where E_i - Electric field of a gas bubble that is immersed in a liquid

ε - Permittivity of liquid

E_0 - Electric field in the liquid in absence of the bubble

- **Breakdown due to liquid globules**

$$E = 487.7\sqrt{\frac{\sigma}{R\varepsilon_\ell}}\ \text{V/cm}$$

Where, E - Critical field on which the globule loses its stability

ε_ℓ - Liquid medium permittivity

σ - Pressure caused by surface tension,

R - Globule radius

Dielectric breakdown of solids- Von Hippel Theory

$$\boxed{E_C = \frac{2\pi^2 v e_m}{h}\left[\frac{1}{n_\infty^2} - \frac{1}{\varepsilon}\right] \text{V/m}}$$

Where,

E_C-Critical field on which the breakdown occurs

v - Optical frequency

n_∞- Index of refraction of infinite wave

ε- Dielectric constant, e_m-Mass of electron

h -Plank's constant

Thermal breakdown :-

Heat generated per unit volume per unit time

$$\boxed{W = E^2 f \cdot \frac{\varepsilon_r \tan\delta}{1.8 \times 10^{12}}} \text{watts/cm}^3$$

Where, E- Uniform electric field

f-frequency

δ - Loss angle

ε_r - Relative permittivity

For direct voltage power dissipated per volume can be given by-

$$\boxed{W = \frac{E^2}{\rho}}\ \text{watts/m}^3$$

Where, $\rho \rightarrow$ Resistivity of the insulator

- **Dielectric loss-** The absorption of electric energy by a dielectric subjected to an alternating electric field is known as dielectric loss.

➢ Dielectric constant-

$\boxed{\varepsilon_r^* = \varepsilon_r' - J\varepsilon_r''}$

- ➢ Imaginary part is incorporated to put absorption of energy in the equation.

$J(t) = \omega\varepsilon_0\,\varepsilon_r''\,E_0\cos\omega t + J\omega\varepsilon_0\,\varepsilon_r'\,E_0\cos\omega t$

J_L = Charging current density

$J_L = \omega\varepsilon_0\,\varepsilon_r''\,E_0\cos\omega t$

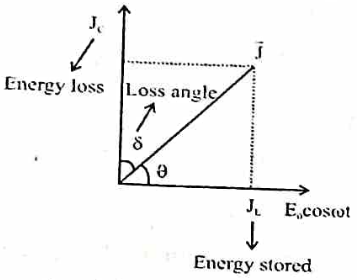
J_C = Lossy current density

$J_C = \omega\varepsilon_0\,\varepsilon_r'\,E_0\cos\omega t$

- **Also loss tangent or dissipation factor –**

$$\boxed{\tan\delta = \left|\frac{J_L}{J_C}\right| = \frac{\varepsilon_r''}{\varepsilon_r'} = \frac{\varepsilon''}{\varepsilon'}}$$

If δ is small $\tan\delta = \delta$, then $\delta = \dfrac{\varepsilon''}{\varepsilon'}$



And energy absorbed

$$\boxed{W(t) = \frac{\omega}{2}\varepsilon_0'\varepsilon_r''E_0^2} \qquad \boxed{W(t) = \frac{\omega}{2}\varepsilon_0\varepsilon_r'\tan\delta E_0^2}\ \text{watt/m}^3$$

- **Dielectric strength-**The maximum electric field that a dielectric material can sustain without breakdown is called its dielectric strength.

Insulating materials	**Dielectric constant**	**Dielectric strength in kV/mm**
Air	1.0006	3.2
Asbestos	2	2
Bakelite	5	15
Epoxy	3.3	20
Glass	5-12	12-100
Marble	7	2
Mica	4-8	20-200
Micanite	4-5-6	25-35
Mineral oil	2.2	10
Mylar	3	400
Nylon	1.8-2.6	16
Paper	1.7-2.3	18
Paraffin wax	2.3	30
Polyethylene	3.6	40
Polyurethane	5-6.7	35
Porcelain	3.7	15
PVC	4.5-4.7	50
Quartz	2.5-4	8
Rubber	2	15-20
Teflon	1	20
Vacuum	2.5-7	Infinity
Wood	2.5-7	------

- **Insulating materials-** Insulating materials block heat transmission, electric current or noise. It has negative temperature coefficient of resistance.

  Ex.- Porcelain, Glass, Neon, Transformer oil, Ceramic etc.

■ Basics of Insulating materials :-

- **Properties of Insulating materials :-**

➢ High voltage bearing capacity

➢ No effect of heat, chemicals, moisture, cold

➢ Electrical properties ➢ Mechanical properties

➢ Visual properties ➢ Thermal properties

➢ Chemical properties

- **Classification of insulating materials :**

  The classification of insulating material is based on the thermal classification, physical classification, structural classification, chemical classification and the process of manufacture.

- **Thermal classification :-**

  Thermally the insulators are classified into seven classes or types. Which are explained below –

i. Class-Y **ii.** Class – A **iii.** Class – E
iv. Class – B **v.** Class – F **vi.** Class – H
vii. Class – C

- **Details of every Insulators :-**

➢ **Class-Y :-** The class-Y temperature limit is 90 °C.

Examples- Cotton, Paper, silk etc.

➢ **Class- A-** Temperature limit of this class material is 105°C

Examples- Paper, silk, polyamide, cotton, resins etc.

➢ **Class- E -** Temperature limit is 120 °C.

Examples- Enameled wire insulation, polyvinyl, epox resins etc.

➢ **Class – B-** Temperature limit is 130 °C.

Examples - Inorganic materials impregnated with varnish.

➢ **Class- F -** Temperature limit is 150 °C.

Examples - Mica, polyester epoxide.

➢ **Class- H-** Temperature limit is 180 °C.

➢ **Class-C -** Temperature limit is greater than 180 °C.

Examples-Glass, Mica, Quartz, Ceramics, Teflon etc.

Other Types of Insulators

Physical classification	Structural classification	Chemical classification	Process of manufacture
Three types- Solid , Liquid, Gases	The Structural classification of insulating material is classified into two types- **i.** Cellulose **ii.** Fibrous	Chemical insulating materials are organic & inorganic.	These are two types **i.** Natural **ii.** Synthetic Insulating materials are – fiberglass, mineral wool, cellulose, natural fibers, polystrene
Solid – Fibrous, ceramic, mica, glass etc			
Liquid- Mineral oils, synthetic oils, transformer oils.			
Gaseous – Air, hydrogen, nitrogen SF_6 etc.			

Conducting Materials

- **Ohm's Law-** $I \propto V$ $\boxed{R = \frac{V}{I},\ R = \frac{\rho \ell}{A}}$

➢ Conductivity $(\sigma) = \frac{1}{\text{Resistivity}(\rho)}$

➢ Current density $(J) = \frac{I}{A}$

Also $\vec{J} = \sigma \vec{E}$ (ohm's law in terms of current density) (Point form of ohm's law)

- **Free electron theory -**

$$\boxed{J = \left(\frac{ne^2T}{m}\right)E = \sigma E},\ \therefore \sigma = \frac{ne^2T}{m}$$

➢ Drift velocity of electron- $\boxed{V_d = \frac{-eET}{m}}$

➢ Current density of electron- $\boxed{\therefore J = -enV_d}$

- **Mobility -** Mobility is known as ease of charge flow in a material. Mobility is defined as drift velocity per unit electric field.

➢ Mobility $(\mu_e) = \boxed{\frac{V_d}{E} = \frac{eT}{m}}$ (m²/volt sec)

➢ For semiconductor –

$$\boxed{\sigma = e\,[n\mu_n + p\mu_p]}$$

- **Joule's Law -** Joule's first law shows the relation between heat produced by flowing electric current through a conductor.

  $H = I^2Rt$

➢ Volume density of heat developed per second W = $\sigma E^2 = JE$ watts/m³

- **Relaxation Time (τ_r , τ_f) -** When electric field applied across a conducting material is removed, the velocity of electrons does not go to zero instantaneously but rather decays exponentially due to inertia of electron. This time is known as relaxation time.

$$\boxed{V_d(t) = V_d(0)e^{-t/\tau_r}}$$

- **Collision time (τ_c)** → Time taken in 2 collisions

➢ it is known as collision time

for isotropic material =

Collision time (τ_c) = Relaxation time (τ_r)

➢ Drift velocity of electron $\boxed{(V_d) = \frac{e\tau_c E}{m} = \mu_c E}$ m/sec.

- **Mean free path :-** Average distance travelled by electron before collision takes place.

$\boxed{\lambda = V\tau_c}$, Where, $V = \sqrt{\frac{3kT}{m}}$

➢ Velocity of an electron $\boxed{V_F = \sqrt{\frac{2E_F}{m}}}$

Where, E_F → Fermi energy

Note – At absolute zero, all energy levels below E_f are filled and all those above E_f being empty.

Factor effecting electrical conductivity of materials :-

i. Temperature **ii.** Alloying

iii. Mechanical stressing → Change in crystal structure

iv. Age Hardening → Age of material↑ → σ↓

v. Cold working → Change in shape without heating it

$$\sigma \propto \frac{1}{T}, \qquad \sigma = \frac{ne^2\tau_c}{m}$$

As temperature ↑, thermal energy ↑, randomness ↑, collisions ↑, τ_c ↓

- mean free path at fermi level $\boxed{d_F = \tau_c\sqrt{\frac{2E_F}{m}}}$

- **Thermal conductivity :-**

➢ Flux of thermal energy $\boxed{Q = -K\left(\frac{dT}{dx}\right)}$ watts/m^2

$\frac{dT}{dx} \rightarrow$ Temperature gradient, °C/m

➢ Thermal conductivity $\boxed{K = \frac{1}{3}\frac{n\pi^2 k^2 \tau T}{m}}$ watt/mK

$\boxed{\frac{K}{\sigma T} = \frac{\pi^2 K^2}{3e^2} = L}$, $\boxed{K = \sigma LT = \frac{LT}{\rho}}$

L (Lorentz Number) = 2.443×10^{-8} W-m/K^2

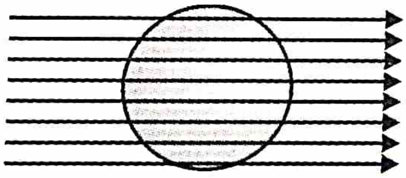
☐ **Super Conductors** - When conductors are cooled to a temperature below a certain value then they lose resistivity and called as super conductor. The temperature at which the metals change from normal conducting state to superconducting state is called Critical temperature/Transition temperature.

Example – Hg, Pb, Zn, PbAu, CuS etc.

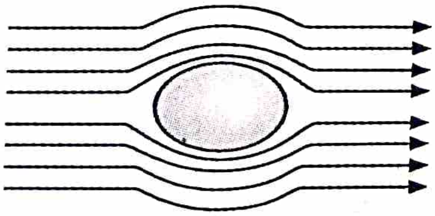
■ Properties of Superconductors –

i. Zero electrical resistance
ii. Persistent currents
iii. Josephson currents
iv. Critical magnetic field
v. Meissner effect → Expulsion of magnetic field
vi. Critical Temperature/Transition Temperature
vii. Critical current

■ **Meissner Effect- Expulsion of magnetic field** – At $\boxed{T > T_c, H < H_c}$ or $\boxed{T < T_c, H > H_c}$ → Magnetic line passes through its body.



➢ When cooled below critical temperature $\boxed{T < T_c, H < H_c}$ - magnetic lines push out of superconductor body.



In the state of super conductivity material exhibits zero resistivity and perfect diamagnetism. For perfectly diamagnetic material

$\chi_m = -1, \ \mu_r = 0, \ B = \mu_0\mu_r H = 0$

■ **Critical field (H_C) -** $\boxed{H_C = H_0\left[1 - \left(\frac{T}{T_C}\right)^2\right]}$

Where H_0 - Critical field at absolute zero temperature

H_C - Critical field at any temperature

T_C-Transition temperature

■ **Silsbee's Rule-** A criterion describing the critical (maximum) value of magnetic field, above which a superconductor loses its superconducting state and becomes a normal resistive conductor. This magnetic field may be generated by current flowing through conductor.

$\oint \vec{H} \cdot d\ell = I$, $H \times 2\pi r = I$

$H = \frac{I}{2\pi r}$, material loses superconducting nature

If $H > H_C$, $I > I_C = H_C 2\pi r$

■ Factors effecting the superconductivity

- **Frequency effect :-** When frequency increases above 10^{13} Hz (infrared Region) material loses its superconductivity.
- **Entropy effect :-** Increase in entropy results in change in state from superconductivity to normal.
- **Isotope effect :-**

$T_C \propto \frac{1}{\sqrt{M}}$, Where, M - mass of isotope

■ Types of superconductors

- **Type –1**

➢ These are ideal superconductors called as soft superconductors.

➢ The critical field and transition temperature values are low.

➢ These exhibit complete Meissner effect and Silsbee's rule.

Example- Th, Pd, Pb, V, Hg etc.

- **Type-2**

➢ These are non- ideal superconductors also called as hard super conductor.

➢ The critical field and transition temperature values are high.

➢ They exhibit incomplete Meissner effect and Silsbee's rule

➢ Change in state from normal to superconducting is gradual.

Example- NBN, $BaBi_3$

MEASUREMENTS AND INSTRUMENTATION

❑ **Methods of Measurement-** There are two method of measurement-

i.	Direct measurement method
ii.	Indirect measurement method

☞ **Remember point**

> Direct method is inaccurate. In this method the unknown quantity is directly compared against a standard.
>
> Indirect method is accurate and more sensitive so this method is more preferred.

- **Instrument -**

Mechanical Instrument	• Unable to respond rapidly •Noisy, heavy and bulky •Use for static and stable condition.
Electrical Instrument	•More rapid than mechanical method. •Some inertia due to mechanical component.
Electronic Instrument	• Very fast response • Mostly used in scientific and industrial measurement

- **Accuracy level -**

Electronics Inst.>Electrical Inst.>Mechanical Inst.

i. **Classification of Instruments -**

Absolute Instruments	• It gives the result in terms of physical constants of the instruments. **Example -** Tangent Galvanometer & Rayleigh's current balance.
Secondary Instruments	• It can be identified by observing the output indicated by the instruments. • It needs calibration by comparison with an absolute instrument. **Example -** Ammeter, Voltmeter, Pressure gauge etc.

ii. **Deflection and Null type Instrument-**

Deflection Instruments	• These type of instruments have less accuracy, less sensitivity but faster response. **Example-** PMMC, Moving iron, Electrodynamometer type inst., Ohmmeter, Megger.
Null Type	• These type of instruments have high accuracy and high sensitivity. **Example-** Potentiometer, Galvanometer

iii. **Recording and Integrated Type-**

Recording type Instruments	• Cathode Ray Oscilloscope (CRO), Substation recording instrument and ECG.
Integrated type instrument	• 1-ϕ Energy meter (Domestic) • 3-ϕ Energy meter (Industrial)

- **Application of Measurement Systems –**

i.	Monitoring of processes and operations.
ii.	Control of processes and operations.
iii.	Experimental engineering analysis.

- **Elements of a Measurement System -**

i.	Primary sensing element.
ii.	Variable conversion element.
iii.	Data presentation method.

- **Measurement System Performance -**

i.	Static characteristics.
ii.	Dynamic characteristics.

- **Static Characteristics of Instruments-**

Accuracy	• The closeness of a measured value to a standard or known value.
Precision	•The closeness of the measurements to each other.
Sensitivity	$\boxed{\text{Sensitivity} = \frac{\text{Small change in output}}{\text{Small change in input}} = \frac{\Delta V_o}{\Delta V_i}}$ $\boxed{\text{Sensitivity} = \frac{1}{\text{Deflection factor}}}$ $\boxed{\text{Sensitivity} = \frac{R_m}{V_{FSD}} = \frac{1}{\left(\frac{V_{FSD}}{R_m}\right)}} \Omega / \text{volt}$ $\boxed{\text{Sensitivity} = \frac{1}{I_{FSD}}} \Omega / \text{volt}$
Repeatability	The repetition of reading of an instrument taken over a period of time.
Reproducibility	It is define as the measure of repeatability of reading an instrument over a period of time.
Dead Time	It is defined as the time required by a measurement system to begin the respond to the change in the measurement.
Dead Zone	It is defined as the range of input value for which there is no output.
Linearity	If the output of any instrument is proportional to the input given to it, then it is called linearty.
Resolution or discrimination	The smallest change in measured value to which the instrument will respond.
Drift	For a particular value of the input, variation in output of an instrument from the desired value. There is no drift for perfect reproducibility.
Static error	It is defined as the difference between the measured value and the true value.

Hysteresis	Hysteresis is a phenomenon which depicts different output effect when loading and unloading.
Threshold	It is minimum measurable input.
Loading effect	Measurement system are used some part of energy from the input system is known as loading effect.

- **Dynamic Characteristics of Instrument**

Speed of response	It is the rapidity with which an instrument responds to changes in the measured quantity.
Measurement lag	It is the time required by an instrument to settle its final steady position after the application of the input.
Dynamic error	It is the difference between the true value of the quantity changing with time.
Fidelity	It is the ability of the system to reproduce the output in the same form as the input.

- **Errors in Measurement and Their Statistical Analysis-**

Static error or Absolute error	δA = Measured value – True value $= A_m - A_T$ δA = Absolute static error A_m = Measured value A_T = True value **Case (i)** If $A_m > A_T$ Then, δA = +ve known error **Case (ii)** If $A_m < A_T$ δA = -ve known error **Case (iii)** if $\delta A = \pm$ ve Unknown error **Note:** It is fixed in respective of reading of the instrument
Statics Correction	$\delta C = A_T - A_m = -\delta A$
Relative limiting error or Percentage error	$\% \varepsilon_r = \left(\dfrac{A_m - A_T}{A_T}\right) \times 100$ $\% \varepsilon_r = \left(\dfrac{\delta A}{A_T}\right) \times 100$ Where, ε_r = Relative limiting error
Range	X_{min} to X_{max}
Span	$X_{max} - X_{min}$
Percentage relative accuracy	$\left[1 - \left\lvert\dfrac{\delta A}{A_T}\right\rvert\right] \times 100$
Guaranteed accuracy error or Accuracy error	$\% \text{ GAE} = \dfrac{\delta A}{\text{Span / FSD}} \times 100$ **Note:** It decreases when the pointer reaches towards full scale value
Error and desired value	$\% \varepsilon_r = \dfrac{\text{Error at full scale}}{\text{Desired value}} \times 100$

Combination of Quantities With limiting errors

- **Sum or Difference of Two or More Than Two Quantities-**

$$y = x_1 \pm x_2$$

$$\frac{\delta y}{y} \times 100 = \pm\left[\frac{x_1}{y} \times \frac{\delta x_1}{x_1} \times 100 + \frac{x_2}{y} \times \frac{\delta x_2}{x_2} \times 100\right]$$

Note : For known error = +ve/-ve
For unknown error ±ve

- **Product or Division of Two or More Than Two Quantities-**

$$y = x_1^m \, x_2^{-n}$$

For known error –

$$\frac{\delta y}{y} \times 100 = \left[\frac{m\delta x_1}{x_1} \times 100 - \frac{n\delta x_2}{x_2} \times 100\right]$$

For Unknown error –

$$\frac{\delta y}{y} \times 100 = \pm\left[\frac{m\delta x_1}{x_1} \times 100 + \frac{n\delta x_2}{x_2} \times 100\right]$$

+ve ⇒ For maximum possibility

Note :

- In case of addition and subtraction, the error in value form simply added but not in percentage form for unknown error.
- In case of multiplication and division, the error in percentage form simply added but not in value form, for unknown error.

Statistical Error

- **Arithmetic Mean Value-**

$$\text{Mean value}\left(\bar{x}\right) = \frac{x_1 + x_2 + \ldots\ldots x_n}{n} = \frac{\sum x}{n}$$

Where, $x_1, x_2, \ldots\ldots x_n$ = Readings
n = No. of readings

- **Deviation-**

$$\boxed{d_n = x_n - \bar{x}}$$

Where, $\bar{x}$ = Mean value of readings
x_n = Readings to the n value

- **Average Deviation-**

Mean or Average deviation -

$$\bar{D} = \frac{\sum |d|}{n} = \frac{|d_1| + |d_2| + \ldots\ldots |d_n|}{n}$$

Note : It indicate the precision of an instrument.

- **Standard Deviation-**

$$\text{S.D.} = \sigma = \sqrt{\frac{\sum d^2}{n}} = \sqrt{\frac{d_1^2 + d_2^2 + \ldots\ldots + d_n^2}{n}}, \text{ For } n > 20,$$

$$\text{S.D.} = \sigma = \sqrt{\frac{\sum d^2}{n-1}} = \sqrt{\frac{d_1^2 + d_2^2 + \ldots\ldots + d_n^2}{n-1}}, \ n \le 20,$$

- **Variance-**

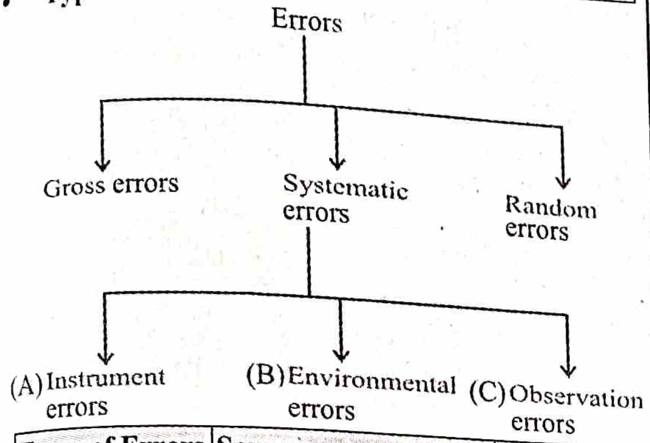
$$\text{Variance } (V) = \sigma^2 = (\text{Standard deviation})^2$$

$$V = \sigma^2 = \frac{\sum d^2}{n}, \quad \text{For } n > 20$$

$$V = \sigma^2 = \frac{\sum d^2}{(n-1)}, \quad n \le 20$$

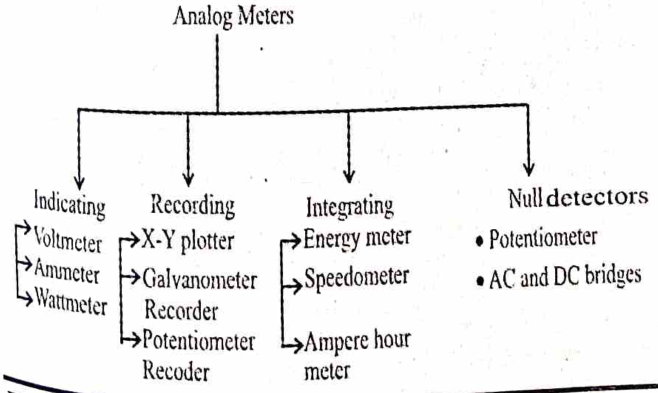
Where, σ = Standard deviation, d = Deviation

- **Types of Errors-**


Errors
Gross errors
Systematic errors
Random errors
(A) Instrument errors
(B) Environmental errors
(C) Observation errors

Types of Errors	Source	Example
Gross Error	The class of error mainly covers human mistakes	Wrong calculation, Misreading, Blunder, wrong selection of instruments
Systematic Error	(A)(i)Due to inherent short comings in the instrument (ii) Due to misuse of the instrument (iii) Due to loading effects of instrument **(B)** These are the error due to temperature humidity and stray magnetic field. **(C)** Parallax error	(A)(i) Use of PMMC with AC. (ii)Frictional error. (iii)Zero not adjust.
Random or Accidental or Residual or Possible error	It's occurs randomly and its magnitude and sign are not known.	

Analog Instruments


Analog Meters
Indicating
Voltmeter
Ammeter
Wattmeter
Recording
X-Y plotter
Galvanometer Recorder
Potentiometer Recoder
Integrating
Energy meter
Speedometer
Ampere hour meter
Null detectors
• Potentiometer
• AC and DC bridges

- **Principles of operation**

Effect	Instruments
Magnetic Effect	Ammeters, Voltmeters, Wattmeters and Energy meters.
Heating Effect	Ammeters and Voltmeters
Electrostatic Effect	Voltmeters
Induction Effect	AC ammeters, Voltmeters, Wattmeters and Energy meters.
Hall Effect	Flux meters, Ammeters and Poynting vector wattmeter.

Electromechanical Indicating Instruments-

- **Operating Torque/ Forces -**

(i) Deflecting Torque
(ii) Controlling Torque
(iii) Damping Torque

- **Deflecting Torque**

$$\boxed{\text{Deflecting torque } (T_d) \propto \text{Measurable quantity}}$$

- **Controlling Torque**

Spring Control	Gravity Control
They should not be magnetic	In this type of control a weight produced a controlling torque due to gravity.
They should be proof from , mechanical fatigue	It must be used in vertical position.
It should have low temperature coefficient of resistance.	It is cheaper
Its most suitable material is Phosphor bronze.	Its control is independent of temperature variations
Flat spiral springs are used.	It does not deteriorate with time.

- **Damping Torque**

Air friction damping	It is used when there is an electromagnet in the instrument **Example-** EMMC, MI
Fluid friction damping	It is used when deflecting torque is poor **Example-** ESV
Eddy current damping	It is preferred when there is permanent magnet is used or where strong magnetic field is available. **Example-** PMMC, Energy meter, Hot wire, induction type.
Electromagnetic damping	When coil move in a magnetic field then due to current a damping torque is developed in the coil. **Example-** Galvanometer, Flux meter.

Note :

(i) Analog instrument are of 2^{nd} order type of instrument which has a damping factor, $\delta = 0.6$ to 0.8, under damped, damping is used.

(ii) T_c depends on T_d but damping torque is independent of T_c and T_d.

- **Preference and Efficient of The Damping Torque**

Preference	Air friction>Eddy current>Fluid friction
Efficient	Eddy current>Fluid friction>Air friction

Analog Ammeters and Voltmeters

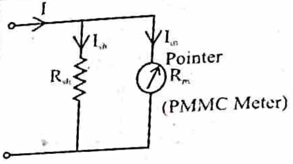
- **Types of Instruments -**

(i) Permanent magnet moving coil (PMMC)
(ii) Moving iron (MI)
(iii) Electro-dynamometer (EDM)
(iv) Hot wire
(v) Thermocouple
(vi) Induction
(vii) Electrostatic
(viii) Rectifier

- **PMMC (Permanent Magnet Moving Coil/ D'Arsonval Instrument)-**

Principle	Magnetic effect
Deflecting Torque	$T_d = BI_mNA$ A = length × breadth = Area
Controlling Torque	Controlling torque is provided by two phosphor bronze hair springs. $T_C = k\theta$
Damping Torque	Damping torque is provided by Eddy current damping.
Scale	The pointer is carried by the spindle and moves over a graduated scale, the pointer is of light weight construction & uniform (linear) scale.
Range	**D.C. Ammeter** • instrument alone $0-5\mu A$ to $0-20mA$ • With internal shunts upto 0-200A • With external shunts, upto-0-5000A **D.C. Voltmeter** • Instrument alone 0-50 or 0-100 mV. • With series resistance upto 20000 - 30000V.
Sensitivity	$S_{pmmc} = \frac{\Delta\theta}{\Delta I_m} = \frac{BAN}{K} \propto \frac{Torque}{Weight}$
Advantages	• No frequency error • Highest internal magnetic field (0.1T to 1T) • Highest sensitivity
	$(20\ k\Omega/V$ to $30\ k\Omega/V)$ • Highest accuracy • Scale is linear
Disadvantage	• It work only with DC • Always reads average value.

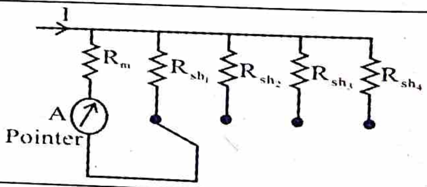
- **Range Extension of PMMC –**
- **Range Extension of Ammeter-**

Shunt material	Manganin constantan
Connection of Shunt	Parallel connection
Property of shunt	• Low resistance • Does not change with temperature
Circuit Diagram	 I I_{sh} I_m Pointer R_{sh} R_m (PMMC Meter) $I = I_{sh} + I_m$ R_m = Resistance of PMMC instrument R_{sh} = Resistance of shunt I = Total input current I_{sh} = Current through shunt I_m = Current through instrument m = Shunt multiplying factor
Value of shunt resistance	$R_{sh} = \frac{R_m}{(m-1)}$, $m = \frac{I}{I_m}$ Where, m = Multiplying factor of shunt

- **Swamp Resistance-**

Function	To eliminated the effect of the temperature
Connection	Series with ammeter
Material	Manganin (DC) , Constantan (AC)
Value	$\boxed{R_{sh} = \left(\frac{R_m + R_{swamp}}{m-1}\right)}$ 20 to 30 times of meter resistance (R_m)

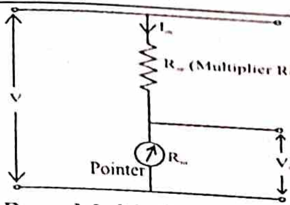
- **For Multi-Range Ammeters-**

Circuit Diagram	 I R_m R_{sh_1} R_{sh_2} R_{sh_3} R_{sh_4} A Pointer
Value	$R_{sh_1} = \frac{R_m}{m_1 - 1}$, $m_1 = \frac{I_1}{I_m}$

- **Range Extension of Voltmeter-**

Used a series multipliers

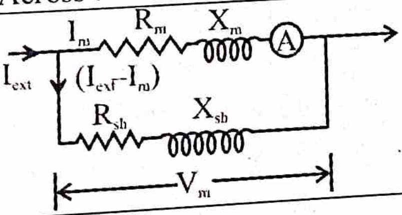
Material	Manganin, constantan
Connection	Series connection

Property	• High resistance • Does not change with temperature
Circuit Diagram	 I_m R_{se} (Multiplier Resistance) V Pointer R_m V_m R_{se} = Multiplier Resistance R_m = Voltmeter Resistance V = Supply Voltage V_m = Voltage across PMMC voltmeter I_{FSD} = Full scale deflection current
Value	$R_{se} = R_m(m-1)$, $m = \frac{V}{V_m}$

- **Moving Iron Instrument (MI)-**

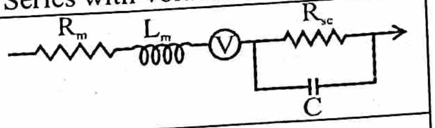
Principle	Magnetic effect
Types	**i.** Attraction type **ii.** Repulsion type
Deflecting Torque	$\boxed{T_d = \frac{1}{2}I^2\frac{dL}{d\theta}}$
Controlling Torque	$\boxed{T_C = k\theta}$ At steady state position $\theta \propto I^2$
Damping Torque	Air friction damping
Scale	Non - linear
Frequency Range	0 to 125 Hz
Advantages	• Universal use for both AC and DC • Less friction error • Cheapness • Robustness
Disadvantages	• Accuracy-less • **Scale**-Non uniform and is cramped at the lower end • **Error-** Due to hysteresis, frequency changes and stray magnetic field • Waveform error • Different calibration between AC and DC

- **Range Extension of MI Type Ammeter**
To extend the range of MI ammeter we connect an impedance across the meter.

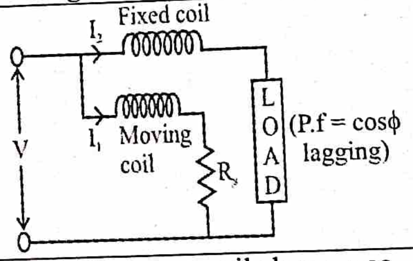
Connection	Across the ammeter
Circuit Diagram	 I_m R_m X_m A I_{ext} $(I_{ext}-I_m)$ R_{sh} X_{sh} V_m
Value	$\lvert Z_{sh}\rvert = \frac{\lvert Z_m\rvert}{\lvert m-1\rvert}$

	Where , $m = \frac{R_m\sqrt{1+\left(\frac{\omega L_m}{R_m}\right)^2}}{R_{sh}\sqrt{1+\left(\frac{\omega L_{sh}}{R_{sh}}\right)^2}} + 1$
Value of m For Independent of Frequency	$\boxed{\frac{L_m}{R_m} = \frac{L_{sh}}{R_{sh}} \Rightarrow \tau_m = \tau_{sh}}$ τ_m = Meter time constant τ_{sh} = Shunt time constant

- **Range Extension of MI Type Voltmeter -**
To extend the range of MI voltmeter we connects a series multiplier

Connection	Series with voltmeter
Circuit	
Value	$R_{se} = (m-1)\lvert Z_m\rvert$ $m = \frac{R_{se}}{\sqrt{R_m^2 + \omega^2 L_m^2}} + 1$
Eliminate Frequency Error	We connect a capacitor in parallel with R_{se}
Value of C	$C = 0.41\frac{L_m}{R_{se}^2}$

- **Electrodynamometer Type Instrument (EDM)**

Principle	Change in mutual inductance
Circuit Diagram	 Fixed coil I_2 I_1 Moving coil V R_s LOAD (P.f = cosϕ lagging)
Construction	EDM have two coils known as fixed coil and moving coil both are air cored.
Deflecting Torque	$\boxed{T_d = i_1 i_2 \frac{dM}{d\theta}}$ At steady state, $\boxed{\theta = \frac{i_1 i_2}{k}\frac{dM}{d\theta}}$
Control Torque	$\boxed{T_C = K\theta}$ Provided by spring control
Damping Torque	Air friction damping
Shielding	Due to low magnetic field (0.005 to 0.006 Wb/m^2) a casing is provided with high permeability alloy.
Cases and Scale	A glass is coated the some conducting material to completely remove the

	electrostatic effect. Most of high precision instruments have a 300mm scale with 100, 120 or 150 division.
Range	**Ammeters** • Fixed and moving coils in series - upto 200 mA • In moving coil ammeter shunted-upto 30A and voltmeter shunted upto 750 V
Frequency Range	Upto 10 kHz
Sensitivity Range	10 Ω/V to 20 Ω/V
Errors	Low torque/weight ratio, frequency error, eddy current, external magnetic fields and temperature changes.
Advantage	• Free from hysteresis error • They have a precision grade accuracy for frequencies upto 40 to 500Hz • Used on both AC and DC, they are very useful as transfer instrument
Disadvantage	• Low torque/weight ratio and hence has a low sensitivity. • More costly than the PMMC or the moving iron type instrument • More sensitive to over loads and mechanical impacts. • Higher power consumption as compared with PMMC • Non uniform scale

- **Electro-Thermic Instruments-**

Principle	**Electro-Thermic Effect**
Types	• Hot wire instrumets → RF instrument → True RMS meter • Thermocouple Instruments • Bolometers
Deflecting Torque	$T \propto I_{rms}^2 \quad E = a\,(\Delta t) + b\,(\Delta t)^2$ follow perfect square law
Control Torque	Spring control
Damping Torque	Eddy current damping
Frequency Range	For MHz
Advantage	• Thermocouple measures rms value of voltage or current . • Not affected by stray magnetic fields. • Free from frequency error and hence they can be used over a very wide frequency range. • They are superior to any other type of instrument both in accuracy and frequency range.

	• Its accuracy high as 1% for frequency upto 50 MHz • High sensitivity • Used as transfer type instrument
Disadvantage	• Over load capacity of thermo-couple instrument is small as compared with other instruments and it is about 150% of the full scale.
Range	• Vacuum type thermo-couple-1.25 mA to 1A • With air cooling fins - 50 A above

- **Electrostatic Instruments -**

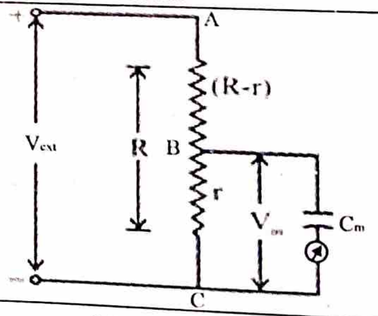
Electrostatic Voltmeter (ESV) :

Principle	• Change in capacitance
Deflecting Torque	• $\boxed{T_d = \frac{1}{2} V^2 \frac{dC}{d\theta}}$
Controlling Torque	• $\boxed{T_C = K\theta}$ $\boxed{\theta \propto V^2}$
Damping Torque	• Fluid friction damping.
Advantage	• Draw negligible power from the supply mains. • Used on both AC and DC • No frequency and waveform error. • No error caused by stray magnetic fields. • For high voltage
Disadvantage	• More expensive, large in size. • Scale is non uniform. • Operating force is small.

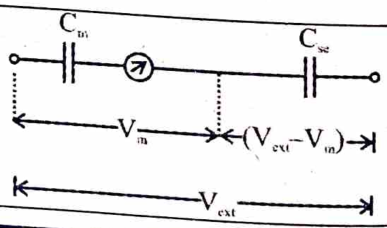
- **Range Extension of Electrostatic Voltmeters-**

There are two method

i. By Using Potentiometer

Circuit Diagram	 + A (R-r) V_{ext} R B r V_m C_m C
Formula	$m = \frac{V_{ext}}{V_m} = \frac{R_{AC}}{R_{BC}} = \frac{L_{AC}}{L_{BC}}$ m = Multiplying factor

ii. By Using Series Capacitance :-

Circuit Diagram	 C_m C_{se} V_m $(V_{ext} - V_m)$ V_{ext}

Formula	$C_{se} = \frac{C_m}{m-1}$ $m = \frac{V_{ext}}{V_m}$ C_m = Capacitance of voltmeter C_{se} = Capacitance in series with voltmeter

- **Rectifier Type Instrument-**

Principle	Magnetic effect
Types	Half wave Rectifier meter Full wave Rectifier meter
Used	For low voltage, low current, low power, high Resistance
Deflecting Torque	$\theta \propto I$
Controlling Torque	Spring Control
Damping Torque	Eddy current damping
Reading	$k_f \times$ PMMC reading
Advantage	• Frequency range 20 Hz to high audio frequencies • Low power consumption except electrostatic • For most ranges, they have a practically uniform scale.
Disadvantage	• Reduced sensitivity ($S_{AC} < S_{DC}$) • Change in diode resistance due to temperature error • One instrument can be used for only one waveform.

- **Half Wave Rectifier Meter -**

Output voltage DC	$(V_o) = V_{DC} = V_{avg} = \frac{V_m}{\pi}$ $(V_o) = V_{avg} = 0.45\ V_{rms}$
Input Voltage	$V_{AC} = \frac{V_m}{\sqrt{2}}$
Form Factor for sin Wave	$\frac{\text{RMS value of AC wave}}{\text{Average value of DC wave}} = 2.22$
F.F. for Saw Tooth Wave	$V_{AC} = 2.30\ V_{DC}$
Reading	2.22 × PMMC reading.
Sensitivity	$S_{AC} = 0.45\ S_{DC}$

- **Full Wave Rectifier Meter-**

Output Voltage	$V_o = V_{DC} = V_{avg} = \frac{2V_m}{\pi}$ $V_{avg} = 0.9\ V_{rms}$
Input Voltage	$V_{AC} = \frac{V_m}{\sqrt{2}}$
Form Factor for sin Wave	$\frac{V_{AC}}{V_{DC}} = \frac{V_m/\sqrt{2}}{2V_m/\pi} = 1.11$
F.F. for Sawtooth Wave	$V_{AC} = 1.15 V_{DC}$
Reading	1.11× PMMC reading
Sensitivity	$S_{AC} = 0.9\ S_{DC}$

Summary of Analog Instruments

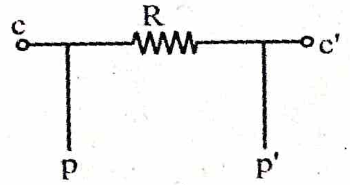
Type	Principle	Controlling	Deflecting	Damping	Power supply	Use
PMMC	Magnetic effect	Spring	$\theta \propto I$	Eddy current	DC	Voltmeter, Ammeter
EMMC (EDM)	Electro magnetic effect	Spring	$\theta \propto I^2$	Air friction	AC or DC	Voltmeter, Ammeter, Wattmeter, Power factor meter, Frequency meter
Moving Iron (MI)	Magnetic effect	Gravity/Spring	$\theta \propto I^2$	Air friction	AC or DC	Ammeter, Voltmeter
Electrostatic	Electrostatic effect	Spring	$\theta \propto V^2$	Fluid friction	AC or DC	Voltmeter
Rectifier	Magnetic effect	Spring	$\theta \propto I$	Eddy current	AC or DC	Ammeter, Voltmeter
Induction Type	Induction effect	Spring	$\theta \propto I_{rms}^2$	Eddy current	AC	Energy meter, Wattmeter, Voltmeter, Ammeter
Hot Wire	Heating effect	Spring	$\theta \propto I^2$	Eddy current	AC or DC	Ammeter, Voltmeter
Thermocouple	Seebeck effect	Spring	$\theta \propto I^2$	Eddy current	AC or DC	Voltmeter, Ammeter

Measurement of Resistance

- **Classification of Resistance-**

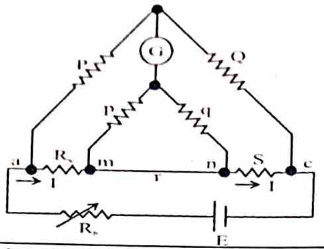
Classification	Value of R
Low resistance	$R \le 1\Omega$
Medium resistance	$1\Omega < R < 100\,k\Omega$
High resistance	$R > 100\,k\Omega$

A. Measurement of low Resistance -

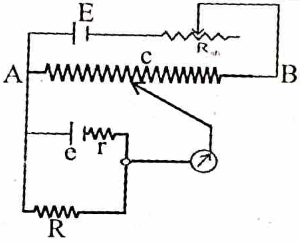
Diagram	Four terminal  Lead resistance

Method	- Kelvin's double bridge method - Potentiometer method

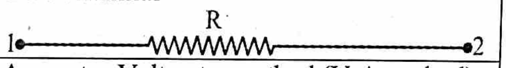
- **Kelvin's Double Bridge Method**

Circuit Diagram	 n G P Q p q a R_x m r n S c I I R_b E
Balance Condition	$\boxed{R_x = \frac{P}{Q}.S + \left(\frac{qr}{p+q+r}\right)\left(\frac{P}{Q} - \frac{p}{q}\right)}$ ➢ Include lead resistance
Eliminate Lead /Contact Resistance	$\boxed{\frac{P}{Q} = \frac{p}{q}}$ then, $\boxed{R_x = \frac{P}{Q}.S}$

- **Potentiometer Method-**

Principle	Based on comparison method.
Circuit Diagram	
Formula	$r = R\left(\frac{L_{AC_1}}{L_{AC_2}} - 1\right)$ $L_{AC_1} > L_{AC_2}$

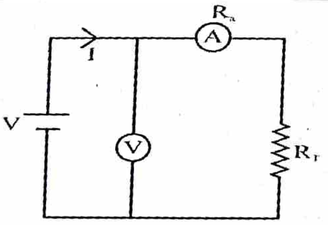
B. Measurement of Medium Resistance-

Diagram	Two terminal 
Method	Ammeter-Voltmeter method (V-A method) Substitution method Wheatstone bridge method Ohmmeter method

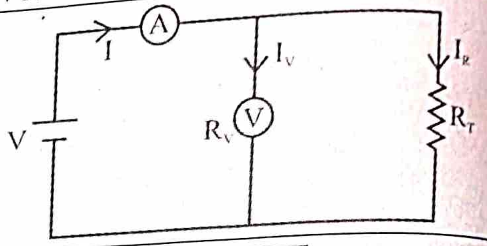
- **Ammeter-Voltmeter Method-**

Principle, $R_m = \frac{V}{I}$

- **Case (i)- Ammeter Near to Unknown Resistance**

Circuit Diagram	 $\boxed{R_m = R_a + R_T}$ R_a = Ammeter internal resistance R_T = Test resistance R_m = Measured value of resistance
Error	$\boxed{\% \text{ error} = \left(\frac{R_m - R_T}{R_T}\right) \times 100}$ $\boxed{\downarrow \% \text{ error} = \left(\frac{R_a \downarrow}{R_T \uparrow}\right) \times 100}$
Use	Best for medium resistance measurement

- **Case (ii)-Voltmeter Near to Unknown Resistance-**

Circuit Diagram	
Error	$\varepsilon_r' = \frac{-R_T}{R_V}$ $\downarrow \% \text{ error} = \frac{-R_T \downarrow}{R_V} \times 100$
Use	Best for low resistance measurement

☞ **Remember point-**

When Error in Both Cases are Same-

$|\varepsilon_r| = |\varepsilon_r'|$

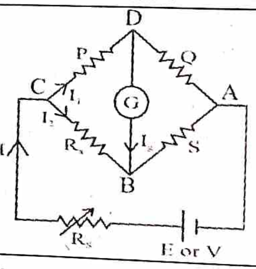
$\frac{R_a}{R_T} = \frac{R_T}{R_V}$ $\boxed{R_T = \sqrt{R_a R_V}}$

R_a = Ammeter internal resistance

R_V = Voltmeter internal resistance

R_T = Test resistance or Unknown resistances

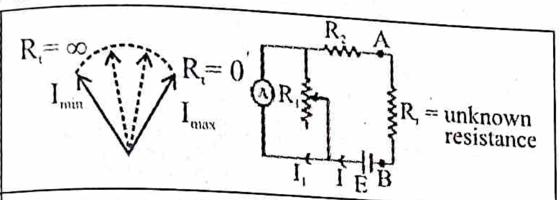
- **Wheatstone Bridge Method-**

Principle	Null deflection
Circuit Diagram	 D P Q C I_1 G A I_2 I R_x I_g S B R_h E or V
Formula	$\frac{P}{Q} = \frac{R_x}{S}$, $R_x = \left(\frac{P}{Q}\right)S$
Error	- Error due to temperature - Error due to contact - Error due to lead resistance - Error due to thermal emf.
Current Sensitivity (S_I)	$\boxed{S_i = \frac{\theta}{I_g}}$ (mm/μA)
Voltage Sensitivity (S_V)	$\boxed{S_V = \frac{\theta}{V_{Th}}}$ (mm/V)

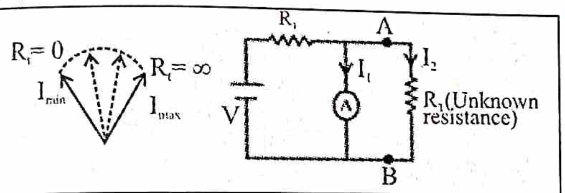
Bridge Sensitivity (S_B)	$\boxed{S_B = \frac{\theta}{(\Delta R/R)}\text{mm}}$ or $\boxed{S_B = \frac{S_v I_g}{(\Delta R/R)}}\text{mm}$
Max Value of Bridge Sensitivity	$\boxed{S_{B_{max}} = \frac{VS_V}{4}}$ occurs when, $\frac{P}{Q} = \frac{R}{S} = 1$

- **Ohm-Meter Method**

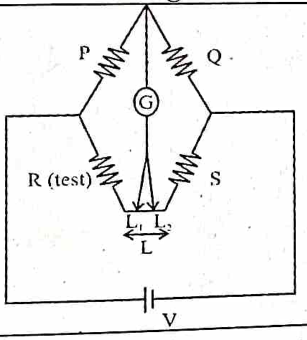
i. **Series Ohmmeter**

Circuit Diagram	 $R_t = \infty$ $R_t = 0$ I_{min} I_{max} R_2 A R_1 R_t = unknown resistance I_1 I E B
Formula	$R_T = R_2\left[\frac{I_{FSD}}{I_m} - 1\right]$ When, AB is open → $I_{min} = I_1 = 0$ and $R_t = \infty = Max$ AB is short → $I_1 = I_{max}$ and $R_t = Min$
Use	For medium resistance, Checking diode, capacitor whether it is all right or damaged

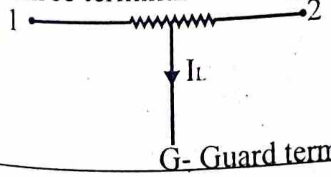
ii. **Shunt Ohm Meter**

Circuit	 $R_t = 0$ $R_t = \infty$ I_{min} I_{max} R_1 A I_t I_2 V R_t(Unknown resistance) B
Result	If R = 0 then $I_m = 0$ if $R = \infty\ \Omega$ then $I_m = I_{max}$. Commonly not used.

- **Carey Foster Slide Wire Bridge-**

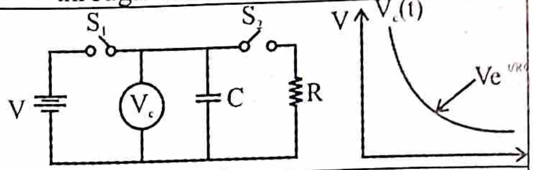
Circuit Diagram	 P Q G R (test) S L_1 L_2 L V
Formula	$\frac{P}{Q}+1 = \frac{R+S+Lr}{S+(L-\ell_1)r}$ ....(i) $\frac{P}{Q}+1 = \frac{R+S+Lr}{R+(L-\ell_2)r}$ .....(ii) $\boxed{R - S = (\ell_2 - \ell_1)r}$
Use	Carey Foster bridge method is used for medium resistance measurement by comparing standard resistance.

C. **Measurement of High Resistance**

Diagram	Three terminal  1 2 I_L G- Guard terminal

Range	R > 100 kΩ
Method	• Loss of charge method • Megger • Direct deflection method • Mega ohm Bridge

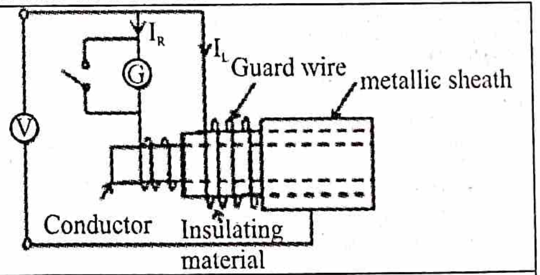
- **Loss of Charge Method-**

Principle	• Charging and discharging of capacitor through unknown resistor.
Circuit Diagram	 S_1 S_2 V V_c C R V $V_c(t)$ Ve
Formula	$\boxed{R = \frac{t}{C\ell n\left(\frac{V}{V_C}\right)}}$ $\boxed{R = \frac{0.4343t}{C\log_{10}\left(\frac{V}{V_C}\right)}}\text{M}\Omega$ Where, t = Time in second V = Supply voltage R = Unknown resistance V_C = Voltage across capacitor

- **Megger Method**

Principle	Based on electrodynamometer.
Formula	$\boxed{\text{Deflection}(\theta) \propto \frac{1}{\text{Unknown resistance }(R_T)}}$ $\tan\theta = \frac{I_2}{I_1},\ \theta \propto \frac{I_2}{I_1}.$
Property	• No need of external supply • Used for the measurement of insulation resistance of cables, bushing insulation. • There is a coil control technique • Megger is a three terminal device

- **Direct Deflection Method-**

Circuit	 I_R I_L G Guard wire metallic sheath V Conductor Insulating material
Reading	$R = \frac{\text{Reading of Voltmeter}}{\text{Reading of Ammeter}}$
Use	• For finding the surface resistivity of an insulator.

❑ Measurement using A.C. Bridges

- **Depending Upon Phase Angle θ, Elements are.**

Phase angle (θ)	Elements
0°	R
90°	L_1
–90°	C_1
0° < θ < 90°	R_1, L
–90°< θ< 0°	R_1, C_1

- **AC Bridges Used For -**

i. Measurement of unknown impedance and associated parameters like inductance, capacitance, and resistance respectively.

ii. Measurement of dissipation factor (tan δ) and electrical permittivity.

iii. Measurement of unknown frequency of audio signal.

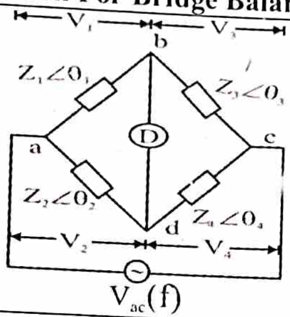
- **Sources-**

a. **For Low Frequency-**Power line supply can be used.

b. **For High Frequency-** Electronic oscillator is used.

AC Bridge-

- **General Equation For Bridge Balance-**

Circuit Diagram	 V₁ V₃ b Z₁∠θ₁ Z₃∠θ₃ D a c Z₂∠θ₂ d Z₄∠θ₄ V₂ V₄ Vac(f)
Condition	$\mid Z_1 \mid\mid Z_4 \mid = \mid Z_2 \mid\mid Z_3 \mid$ $\angle\theta_1 + \angle\theta_4 = \angle\theta_2 + \angle\theta_3$
Detector	Vibration Galvanometer- 5Hz to 1 kHz Headphone - 250 Hz to 4 kHz Tuned Amplifier - 10Hz to 100 kHz D'Arsonval Galvanometer – 0 Hz

- **Measurement of Self Inductance-**

i. Maxwell's Bridge -
(1<Q<10) - It measures medium Q of coil

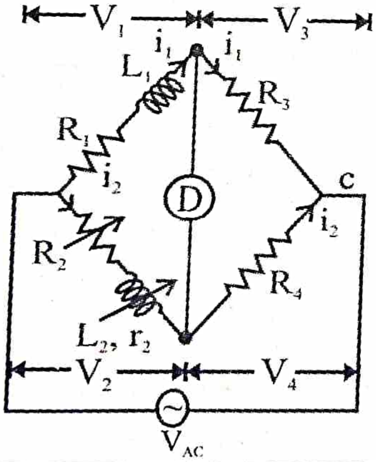
ii. Maxwell's Inductance Capacitance Bridge

iii. Hay's Bridge(Q>10) - It measures high Q of coil

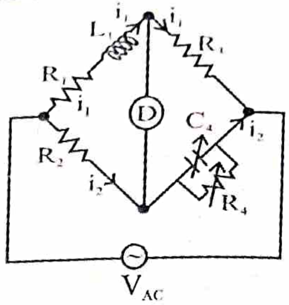
iv. Anderson's Bridge (Q<1) - It measures low Q of coil

v. Owen's Bridge- It measure incremental inductance

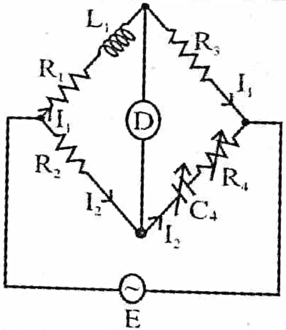
i. Maxwell's Inductance Bridge-

Circuit Diagram	 V₁ V₃ i₁ i₁ L₁ R₃ R₁ i₂ c D i₂ R₂ R₄ L₂, r₂ V₂ V₄ VAC
Formula	$R_1 = \frac{R_3}{R_4}(R_2 + r_2)$ $L_1 = \frac{R_3}{R_4}.L_2$ Where , L_1= Unknown inductance L_2 = Variable inductance R_2 = Variable resistance R_3, R_4 → Known non-inductive resistance. R_1 = Unknown resistance

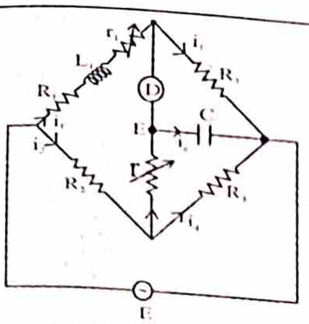
ii. Maxwell's Inductance Capacitance Bridge-

Circuit Diagram	 i₁ i₁ L₁ R₃ R₁ i₁ D C₄ i₂ R₂ i₂ R₄ VAC
Formula	$R_1 = \frac{R_2R_3}{R_4}, L_1 = R_2R_3C_4$ $Q = \frac{\omega L_1}{R_1} = \omega C_4 R_4$
Range	It measures medium Q of coil (1< Q < 10)
Advantage	Useful for the measurement of a wide range of inductance at power and audio frequency
Disadvantage	Very expensive due to standard capacitor

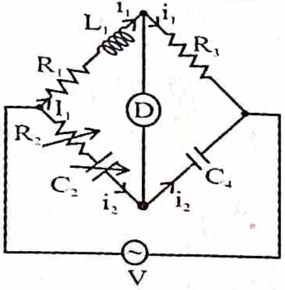
iii Hay's Bridge-

Circuit	 L₁ R₃ R₁ I₁ I₁ D R₂ R₄ I₂ C₄ I₂ E
Formula	$L_1 = \frac{R_2R_3C_4}{\left(1+\omega^2R_4^2C_4^2\right)}$ $R_1 = \frac{\omega^2R_2R_3R_4C_4^2}{1+\omega^2R_4^2C_4^2}$ $Q = \frac{1}{\omega R_4 C_4}$
Range	Q > 10
Advantage	Very simple for high Q
Disadvantage	It is slowest bridge

iv. Anderson's Bridge

Circuit Diagram	 r₁ i₁ L₁ R₁ R₃ D E C i₂ r R₂ R₄ E
Formula	$R_1 = \frac{R_2R_3}{R_4} - r_1$ $L_1 = C\frac{R_3}{R_4}[r(R_4+R_2)+R_2R_4]$
Range	Very low Q of coil (Q < 1)
Advantage	Used for accurate determination of inductance in terms of capacitance
Disadvantage	More complex than its prototype maxwell's bridge

v. **Owen's Bridge-**

Circuit Diagram	 i₁ L₁ i₁ R₃ R₁ D R₂ C₂ i₂ i₂ C₄ V
Formula	$L_1 = R_2R_3C_4$ $R_1 = \frac{C_4}{C_2}R_3$ $Q = \frac{\omega L_1}{R_1} = \omega R_2C_2$
Measure Quantity	• It is used for the measurement of self inductance with a wide range. • Used for measurement of incremental inductance. • Suitable for medium Q-factor measurement.
Advantage	Equation are quite simple and do not contain any frequency component.
Disadvantage	Value of capacitance C_2 becomes high when measuring High Q Coil.

• **Measurement of Mutual Inductance-**

(i) Heaviside mutual inductance bridge

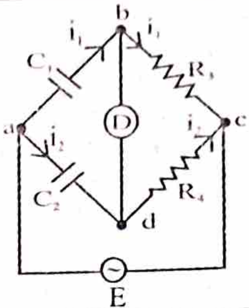
(ii) Campbell bridge

(iii) Carey Foster bridge- Heydweiller bridge

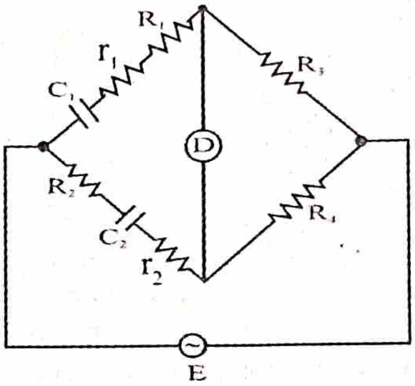
■ Measurement of capacitance-

1. De-Sauty's bridge-

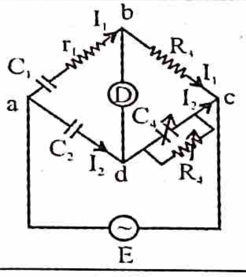
i. **For Loss Less Capacitors**

Circuit Diagram	 b i₁ i₁ C₁ R₃ D a c i₂ i₂ C₂ R₄ d E
Formula	$C_1 = \frac{R_4}{R_3}C_2$

➢ **For Lossy Capacitors**

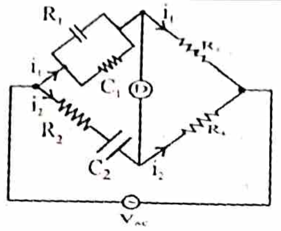
Circuit	
Formula	$r_1 = (R_2 + r_2)\left(\frac{R_3}{R_4}\right) - R_1$ $C_1 = \frac{R_4}{R_3}.C_2$

2. Schering Bridge

Circuit	 I₁ b r₁ R₃ C₁ I₁ a D c I₂ C₄ C₂ I₂ d R₄ E
Formula	$r_1 = \frac{C_4}{C_2}R_3 \qquad C_1 = \frac{R_4}{R_3}C_2$ $D = \tan\delta_1 = \omega C_1 r_1 = \omega C_4 R_4$
Use	• Use for measurement of relative permittivity and power factor of dielectric materials. • Schering bridge method is used for the measurement of dissipation factor and capacitance
Precaution	Earthed screen are provide to reduce inter- arm capacitance.

Measurement of Frequency-

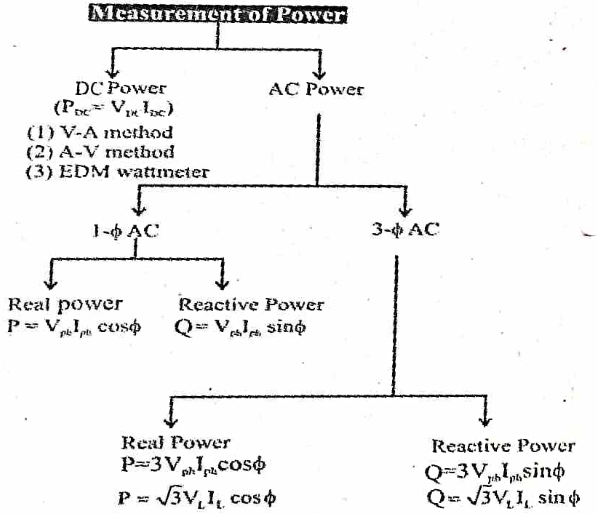
i. Wien's Bridge-

Circuit Diagram	 R₁ i₁ C₁ D R₃ i₂ R₂ C₂ i₂ R₄ V_ac
Formula	$\boxed{f=\frac{1}{2\pi\sqrt{R_1R_2C_1C_2}}}$ If $C_1 = C_2 = C$, $R_1 = R_2 = R$ $\boxed{f=\frac{1}{2\pi RC}}$
Disadvantage	High sensitive with respect to harmonics

- **Source of Error in Bridge Circuit**

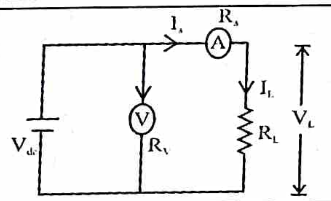
(i) Stray conductance effect
(ii) Mutual inductance effect
(iii) Stray capacitance effect
(iv) Residuals in components

- **Wagner Earthing Device**
- Eliminate the effect of earth capacitors

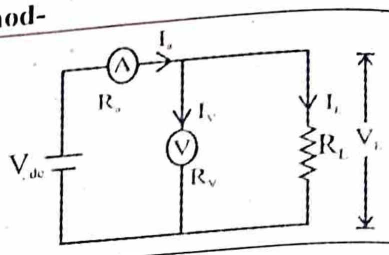

Measurement of Power
DC Power
($P_{DC} = V_{DC} I_{DC}$)
(1) V-A method
(2) A-V method
(3) EDM wattmeter
AC Power
1-ϕ AC
3-ϕ AC
Real power
$P = V_{ph}I_{ph}\cos\phi$
Reactive Power
$Q = V_{ph}I_{ph}\sin\phi$
Real Power
$P = 3V_{ph}I_{ph}\cos\phi$
$P = \sqrt{3}V_LI_L\cos\phi$
Reactive Power
$Q = 3V_{ph}I_{ph}\sin\phi$
$Q = \sqrt{3}V_LI_L\sin\phi$

DC Power Measurement

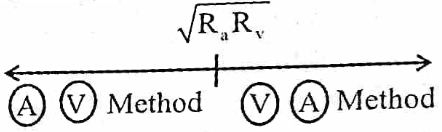
1. V - A method-

Circuit Diagram	 Iₐ Rₐ A V_dc V R_v I_L R_L V_L
Formula	$\boxed{P_m = P_T + I_a^2R_a}$ $\boxed{P_T = I_a^2R_L}$ $\boxed{\text{Error} = +\text{Ve} \Rightarrow P_m - P_T}$ $\boxed{\downarrow\%\ \text{Error} = \frac{P_m - P_T}{P_T}\times 100 = \frac{R_a}{R_L\uparrow}\times 100}$
Use	Best for high resistive load

2. A-V method-

Circuit	 I_L A Rₐ I_V V_dc V R_V I_L R_L V_L
Formula	$\boxed{P_m = P_T + \frac{V_L^2}{R_V}}$ $\boxed{\text{Error} = +\text{ve} \Rightarrow P_m > P_T}$ $\%\ \text{Error}\downarrow = \frac{I_V}{I_L\uparrow}\times 100$ $\%\ \text{Error}\downarrow = \frac{R_L\downarrow}{R_V}\times 100$ $\boxed{\%\ \text{Error} = \frac{P_m - P_T}{P_T}\times 100}$
Used	Best for low resistive load.

- **Condition For Equal Error in Both Condition-**


$\sqrt{R_aR_v}$
Ⓐ Ⓥ Method
Ⓥ Ⓐ Method

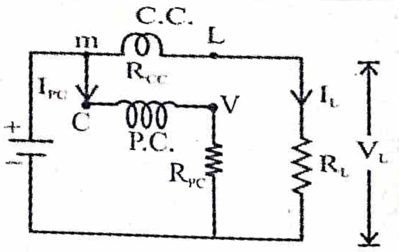
$\boxed{R_a = \left(\frac{V_L}{I_L}\right)^2\times\frac{1}{R_V}}$ $R_L = \sqrt{R_aR_v}$

AC Wattmeter-

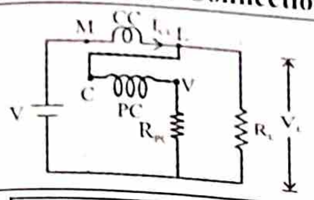
- ➢ Electro dynamometer type wattmeter
- ➢ Electrostatic wattmeter - Precision or Laboratory type
- ➢ Inductance type wattmeter- Only AC power measurement
- ➢ Thermocouple wattmeter

1. Electrodynamometer Wattmeter-

a. Connection (1) M-C Short Circuit-

Circuit Diagram	 C.C. m L R_CC I_PC C V P.C. R_PC I_L R_L V_L +C.C. - Current Coil/Fixed Coil P.C. - Pressure Coil/Moving Coil R_{CC} - Resistance of Current Coil R_{PC} - Resistance of Pressure Coil
Formula	$\boxed{P_m = P_T + I_L^2R_{CC}}$, $\boxed{I_{CC} = I_L}$
Error	Due to power loss in current coil.

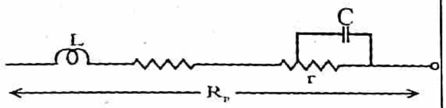
b. **Connection (2) L-C Short Connection-**

Circuit Diagram	
Formula	$\boxed{P_m = P_T + \frac{V_L^2}{R_{PC}}}$ $\boxed{I_{CC} = I_L + I_{PC}}$
Result	Current coil/Fixed coil → N ↓,A↑ Voltage coil-N↑,A↓
Error	Due to power losses in pressure coil

Error in Electrodynamometer Wattmeter

- Error due to pressure coil inductance.
- Error due to pressure coil capacitance.
- Error due to method of connection.
- Stray magnetic field error
- Error due to moving system
- Temperature error

Error due to Pressure Coil Inductance-

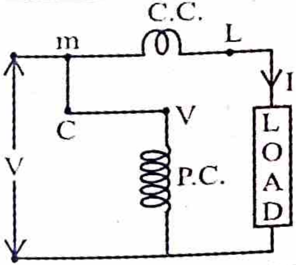
Correction Factor	$\boxed{\text{Correction factor} = \frac{\cos\phi}{\cos\beta\cos(\phi\pm\beta)}}$ -ve → Lagging load +ve → Leading load
Compensation	• Bifilar winding • Connect a capacitor in parallel with resistance of the value of, $\boxed{C = \frac{L}{r^2}}$ 

Error due to Pressure Coil Capacitance-

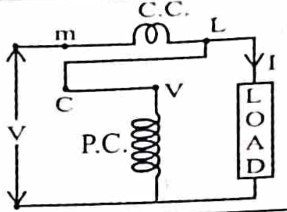
Source	This capacitance is due to, inter-turn capacitance of the series resistance.
Effect	Due to this capacitance the wattmeter reads high on lagging power factor of the load.
Compensation	To eliminate these error $\boxed{X_L = X_C}$ of the pressure coil.

Error Because of Connection

i. **M-C Short Connection-**

Connection	
Reading	Power indicated by wattmeter = Power consumed and power losses by load + Power consumed in current coil
Prefer	When load current is small

ii. **L-C Short Connection**

Connection	
Reading	Power indicate by wattmeter = Power consumed by load + Power loss in P.C.
Prefer	When load current is large

- **Low Power Factor Electrodynamometer type Wattmeter-**

These are modification of the Electrodynamometer type wattmeter for reading of low power factor wattmeter.

Power measurement in Polyphase System

- **Blondel's Theorem**

(i) For 'n' phase n wire system (n – 1) wattmeter requires (Balance/unbalance)

(ii) For n phase (n + 1) wire system n wattmeter requires (unbalance)

(iii) For n phase (n + 1) wire balance system 1 wattmeter require

Measurement of Power in 3-ϕ Circuit

- **Two-Wattmeter Method-**

For inductive load	$W_1 = V_L I_L \cos(30^0 - \phi)$ $W_2 = V_L I_L \cos(30^0 + \phi)$ $W = W_1 + W_2 = \sqrt{3} V_L I_L \cos\phi$
For capacitive load	$W_1 = V_L I_L \cos(30^0 + \phi)$ $W_2 = V_L I_L \cos(30^0 - \phi)$ $W = W_1 + W_2 = \sqrt{3} V_L I_L \cos\phi$

- **Measurement of 3-ϕ Reactive Power-**

$$W_1 - W_2 = V_L I_L \sin\phi$$
$$Q = \sqrt{3}(W_1 - W_2)$$
$$Q = \sqrt{3} V_L I_L \sin\phi$$

- **Reading of two Wattmeter (Load is lagging) :-**

ϕ	cosϕ	Relation between W_1 & W_2
0°	1 (UPF)	$W_1 = W_2$
30°	0.866 lag	$W_1 = 2W_2$
60°	0.5 lag	W_1 = reads, $W_2 = 0$
0° < ϕ < 60°	0.5< cos ϕ < 1	$W_1 = +ve, W_2 = +ve$
90°	0	$W_1 = -W_2$
60°< ϕ < 90°	0 < cosϕ < 0.5	$W_1 = +ve$ $W_2 = -ve$

Note :

At zero power factor, the readings of the two wattmeter are equal but of opposite sign. When the power factor is below 0.5, one of the wattmeter will give negative indication. Under these conditions in order to read the wattmeter, we must either reverse the current coil or the pressure coil connection.

The wattmeter will give a positive reading but this must be taken as negative for calculation of the total power.

■ Measurement of Reactive Power

i. Single Phase VAR meter:-

This is an electrodynamic wattmeter in which pressure coil circuit has a large inductance which is substituted for the series resistance so that the pressure coil current is in quadrature with the voltage.

$VI\cos(90-\phi) = VI\sin\phi$

ii. Poly-Phase VAR meters

For balanced load- Use a single wattmeter

Current coil → Connected in one line

Pressure coil → Connected across the other two line

■ Measurement of Energy-

- $\text{Energy} = \text{Power} \times \text{time},\ E = \int_0^t P\,dt$
- Unit → Kilowatt hours or Watt – second or Joule
- Energy meter is used to measure the energy consumed by load.

- **Energy meter**

➢ Integrating type instrument

➢ Principle based on induction

➢ No controlling torque

- **Single Phase Induction Type Watt Hour Meter**

Driving system	Uses two electromagnet, shunt and series coil
Moving system	It consists of an aluminium disc mounted on a light alloy shaft
Braking system	A permanent magnet positioned near the edge of the aluminium disc forms the braking system.
Registering (Counting mechanism)	A train of reduction gears the pinion on the rotor Aluminium disc forms the braking system

- **Braking Torque (T_b)**

➢ Speed of disc ∝ power consumed by the load

$$\boxed{T_b = \frac{k\phi^2 Nx}{R}}$$

Where,

R = Resistance of Al disc

ϕ = Flux of permanent magnet

x = Distance of Al disc from permanent magnet

N= Speed of Al disc in (rpm)

Note : If the load is constant

Power = Constant then,

$T_d = T_b$= Constant

➢ Due to heat $\left(I_e^2R\right)$, temp $\uparrow$ $(\alpha = +ve)$

$$R\uparrow, \frac{N}{R} \propto \text{Constant}, \quad \Rightarrow \uparrow N \propto R \uparrow$$

➢ If $x\uparrow$ $Nx = \text{Constant}, N\downarrow$

➢ $\phi\uparrow, \downarrow N \propto \frac{1}{\phi^2\uparrow}$

$$\phi \to \infty, N \to 0$$

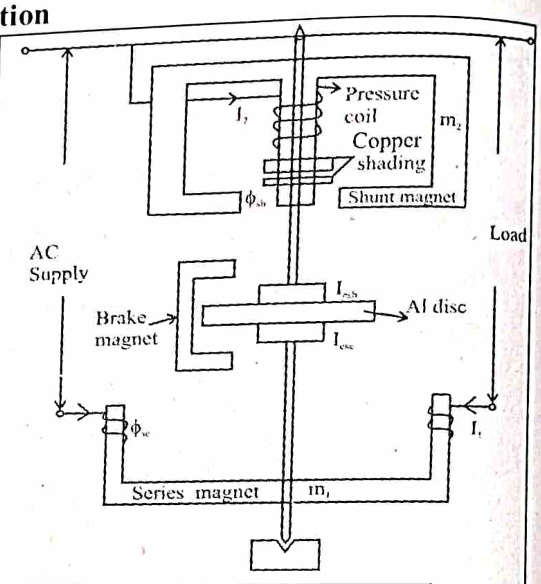
- **Registering System**

➢ Used to directly note the energy in kWh.

Meter constant (K),

$$K = \frac{\text{Rotation made by } A\ell \text{ disc(revolution)}}{\text{Energy consumed by the consumer(kWh)}}$$

- **Construction**

Circuit	 Pressure coil Copper shading I_2 m_2 ϕ_{sh} Shunt magnet Load AC Supply I_{esh} Al disc Brake magnet I_{ese} ϕ_{se} I_1 Series magnet m_1 Shunt magnet $\to I_2 \to \phi_{sh} \to I_{esh}$ Series magnet $\to I_1 \to \phi_{se} \to I_{ese}$
Pressure coil	• Highly inductive • Connected across the supply
Reading	**Case I:** Series coil resistance = 0 Shunt coil assumed to be pure inductive $\overline{Z}_{sh} = 0 + jX_{sh}$ $\beta = \frac{\pi}{2}$ then, $\boxed{T_d \propto P_T}$ no error **Case II:** Shunt coil has resistance $\overline{Z}_{sh} = R_{sh} + jX_{sh}$ $\beta = \tan^{-1}\left(\frac{X_{sh}}{R_{sh}}\right)$ $T_d \propto I_{sh}I_{se}\sin(\beta-\theta)$ Have some error
Cause of error	• Incorrect magnitude of fluxes • Incorrect phase angle • Lack of symmetry in magnetic circuit • Resistance of shunt coil

- **Compensation of 1-ϕ Energy Meter**

Lag compensation	Through lag coil or shading coil
Low load or friction adjustment	By using shading loop
Over friction or Creeping	By providing holes or slots on rotating disc.
Over load compensation	By keeping saturable shunt magnet in series magnet.
Over Voltage Compensation	Provided by increasing the reluctance of the side limbs of the shunt magnet.
Temperature Compensation	Making permanent magnet of "MUTEMP" material
Speed Adjustment	Adjusting the position of break magnet

- **Adjustment-** For correctly read some adjustment-

➢ Primary light load adjustment
➢ Full load unity factor adjustment
➢ Lag adjustment (Low power factor adjustment)
➢ Light load adjustment
➢ Creep adjustment

- **Creeping Error**

Causes	• Over static friction compensation • Over voltage • Excessive lubrications • Vibration • Stray magnetic field
Eliminate	Two holes are drilled on opposite side of the disc By an iron piece
Magnitude	$\% \text{Creeping error} = \dfrac{\text{Revolution of disc to creeping per hour}}{\text{Revolution of disc due to total load per hour}} \times 100$

- **Percentage Error in Energy Meter**

$$\text{Percentage error} = \boxed{\dfrac{\dfrac{N_x}{K_x} - \dfrac{N_s}{K_s}}{\dfrac{N_s}{K_s}} \times 100}$$

Where,

K_x – Number of revolutions /kWh under test.
K_s – Number of revolution/kWh for the standard.
N_x – Number of revolutions for certain number.
N_s – Number of revolutions for standard.

- **Temperature Compensation**

Effect	Meter runs fast and resistance is too high.
Eliminate	• Using a temperature shunt on the brake magnet special magnetic material such as MUTEMP. • MUTEMP decreases the permeability with the increases in temperature

- **Phantom Loading**

This loading phenomenon comes in the calibration of energy meter, in which the power consumption of current coil get reduced in calibration work.

Potential coil → Rated voltage

Current coil → Low voltage DC battery

Some Special Purpose Instrument

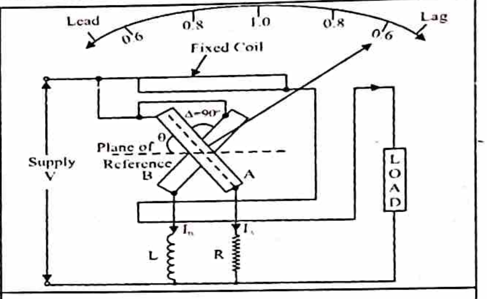
- **Maximum Demand Indicator**

Maximum demand indicator must be designed to record the average power over successive predetermined. These periods may be of 15 to 30 minutes duration.

- **Types :**

➢ Recording demand indicators
➢ Average demand indicators (Merz price maximum demand indicator)
➢ Thermal type maximum demand indicator
➢ Digital maximum demand indicator

Power Factor Meter

Circuit Diagram	 Lead 0.6 0.8 1.0 0.8 0.6 Lag Fixed Coil Δ-90° θ Plane of Reference Supply V B A I_R I_L L R LOAD
Formula	$\dfrac{P}{S} = \dfrac{kW}{kVA} = \dfrac{\text{Active power}}{\text{Apparent power}}$
Construction	• **Pressure circuit-** It is splitted in two parallel paths. (i) Indicative (ii) Non-inductive • Current circuit • Moving system-balance • Controlling torque-not required
Types	• Electrodynamometer type • Moving iron type

- **Single phase electrodynamometer power factor meter**

Moving coil- Angle between planes of coil is exactly 90^0

Designed and calibrated - Only one frequency

- **Three phase Electrodynamometer power factor meter**

Moving coil- Two moving coils are placed at 120^0

Designed and calibrated-All frequency.

Frequency Meter

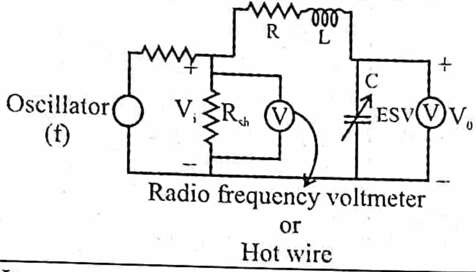
- **Types of Frequency Meter-**

➢ Mechanical resonance type/ Vibrating reed type
➢ Electrical resonance type
➢ Electrodynamometer type
➢ Western type
➢ Ratio meter type
➢ Saturable core type

- **Mechanical Resonance Type (Vibrating reed type)**

Value of reed	4mm wide, $\frac{1}{2}$ mm thick
Arranged	Ascending order
Difference in frequency	$\frac{1}{2}$Hz
Range	7 Hz to 53 Hz
Advantage	Independent of the waveform of the supply voltage.
Disadvantage	Can not read much closer than half the frequency difference between adjacent reeds.

▨ Quality Factor Meter-

Circuit Diagram	 R L C + + Oscillator (f) V_i R_{sh} V ESV V V₀ – – Radio frequency voltmeter or Hot wire
Measure	It measures quality factor of a coil
Principle	It based on series resonance.
Formula	$Q = \frac{\omega L}{R}$
Distributed Capacitance	$\boxed{C_d = \frac{C_1 - n^2C_2}{n^2 - 1}}$ Where, $f_2 = nf_1$ $f_1 = \frac{1}{2\pi\sqrt{L(C_1 + C_d)}}$ $f_2 = \frac{1}{2\pi\sqrt{L(C_2 + C_d)}}$
Error	• Error due to R_{sh} $\%E = \frac{-R_{sh}}{R + R_{sh}} \times 100$ • Error due to distributed capacitance $\%E = \frac{-(C_d)}{(C + C_d)} \times 100$
Application	• Resistance • Quality factor • Inductance • Bandwidth • Self or Distributed capacitance • Capacitance of a coil

▨ Cathode Ray Oscilloscope (CRO)

Principle	Thermoinic emission
Other name	•Electronic voltmeter •Voltage sensitive element
Measure	•RMS, Peak and Average value of signals •By using different modes we can also measures phase, frequency and time period
Mode	(i) y-t mode (ii) x-y mode
Component	• CRT • Vertical amplifier • Horizontal amplifier • Delay line • Triggering circuit • Time base generator

1. CRT (Cathode Ray Tube)

A. Electron Gun

Heating element	Used to heat up the cathode connected with 6.3V, 600 mA supply.
Cathode	Used Ni cylinder with having a coating of BaO or SrO
Control grid	Used to control the number of electron provided with –ve voltage.
Pre-accelerating anode	Used Ni cylinder to accelerate the electron beam and provided with +1500V
Focusing anode	Used to focus the electron beam Electrostatic focusing technique is use.
Post accelerating anode	Used to increase the brightness.

B. Deflecting System

Horizontal deflecting plate	• Deflect the electron beam horizontally • It is placed vertically • It is also known as x-plate
Vertical deflecting plate	• It deflects electron beam vertically • It is placed horizontally and also known as y-plate.
Formula	$Y = \frac{1}{2}\frac{V_d x\ell}{V_a d}$ V_d= Deflecting plate voltage (V) ℓ= Length of plate (m) Y= Electrostatic deflection (m) x= Distance of screen from center of plates V_a= Accelerating potential (V)
Sensitivity	$S_{CRO} = \frac{\Delta Y}{\Delta V_d} = \frac{x\ell}{2V_a d}$ m/V

C. Screen-

- The wall of CRT is coated with phosphor.
- The material like silver, manganese, copper and Chromium is added to phosphor material to increase the persistence luminous efficiency.

- **Aquadag-** Aqueous solution of Graphite is used to absorb the secondary emitted electron

2. **Time base generator**

It generate the saw tooth wave (sweep wave)

$$B.W = \frac{0.35}{t_r}$$

Where, B.W = Bandwidth, t_r = Rise time

3. **Oscilloscope Amplifier**

- Horizontal amplifier
- Vertical amplifier

4. **Delay Line**

To match the signal at vertical deflection plate and horizontal deflection plate.

- **Mode of Operation of CRO**

Normal mode	• Measured voltage and current • **x-plate input-** saw tooth signal • **y-plate input-** unknown signal
Dual mode	• Measured frequency, phase difference • **x-plate input-** unknown signal • **y-plate input-** unknown signal

Lissajous Pattern-

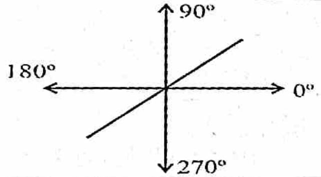
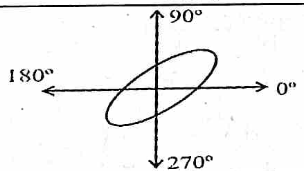
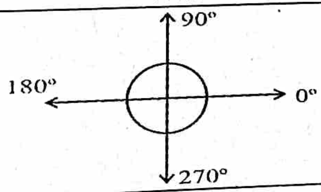
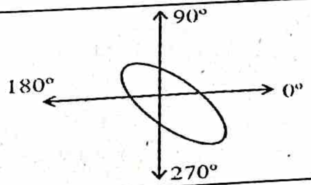
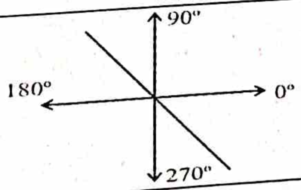
1. Frequency Measurements

$$\frac{f_y}{f_x} = \frac{\text{Max.no.of intersection of a horizontal line with Lissajous pattern}}{\text{Max.no. of intersection of a vertical line with Lissajous pattern}}$$

f_y = Unknown frequency

f_x = Known frequency

2. Phase Angle Measurement

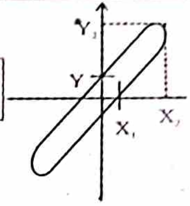
Phase angle (ϕ) between V_x and V_y	**Lissajous pattern**
0° or 360° Straight line I and III	
$0° < \phi < 90°$ or $270° < \phi < 360°$ Ellipse I & III	
$\phi = 90°$ or 270° Circle	
$90° < \phi < 180°$ or $180° < \phi < 270°$ Ellipse II & IV	
$\phi = 180°$ Straight line II & IV	

☞ Remember Point

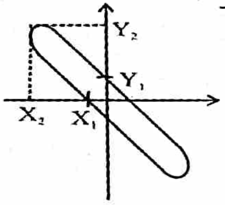
- Lissajous figure from 0° to 180° → Clock wise
- Lissajous figure from 180° to 360° → Anti clock wise

Finding the Phase Angle ϕ from given Lissajous Pattern-

a. When lissajous pattern is in 1st and 3rd quadrant-

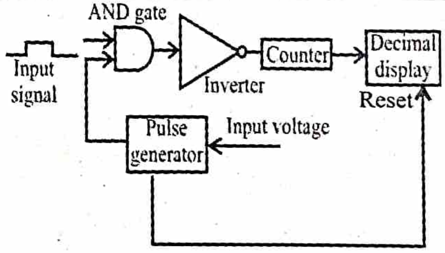
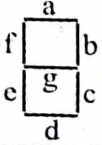
First possibility	$\phi = \sin^{-1}\left(\frac{X_1}{X_2}\right) = \sin^{-1}\left(\frac{Y_1}{Y_2}\right)$ 
Second possibility	$\boxed{360^0 - \phi}$

b. When Lissajous pattern is in second and fourth quadrant –

First possibility	$\phi = 180° - \sin^{-1}\left(\frac{x_1}{x_2}\right)$ OR $\phi = 180° - \sin^{-1}\left(\frac{y_1}{y_2}\right)$ 
Second possibility	$\boxed{360 - \phi}$

Digital Voltmeter

- It is a voltage sensitive device

Circuit Diagram	 AND gate Input signal Inverter Counter Decimal display Reset Pulse generator Input voltage
Construction	• Input signal- Voltage to be measured • Pulse generator- To generate rectangular pulse • Width and frequency control- By digital circuit • Amplitude, rise and fall time control-By analog circuit. • Decimal display- Display the value of voltage on LED. 

Input impedance	10 MΩ
Range of resolution	10^{-6} V
Types	• Ramp type digital voltmeter • Integrating type voltmeter • Potentiometric type voltmeter • Successive approximation type • Continuous balance type DVM
Advantage	• High versatile • High accuracy • High resolution • Reduce size • Less power consumption and less cost
Formula	Resolution of DVM $= \frac{1}{10^N}$ N= Number of full digits Sensitivity= resolution × range of meter

- **Dual Slope Integrating DVM**

It is most accurate DVM-

1. $V_m T_1 = V_{ref} \cdot T_2$ **2.** $V_m = \left[\frac{V_{ref}}{10^N}\right].X$

3. Conversion time = $T_1 + T_2$

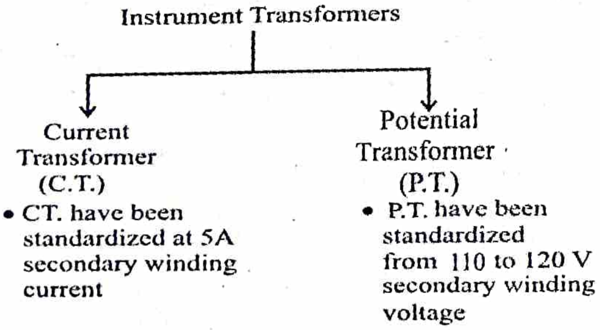
4. Design criteria for noise rejection $T_1 = nT_s$

$$T_1 = \frac{10^N}{f_{clk}}, \qquad T_s = \frac{1}{50\text{ Hz}}$$

$$\boxed{\frac{10^N}{f_{clk}} = \frac{n}{50\text{Hz}}}$$

Where, V_m = Unknown analog voltage signal
V_{ref} = Reference voltage in DVM
$T_1 = 1^{st}$ Integration time period
$T_2 = 2^{nd}$ Integration time period
T_s = Noise signal time period

Instrument Transformer


Instrument Transformers

Current Transformer (C.T.)
- CT. have been standardized at 5A secondary winding current

Potential Transformer (P.T.)
- P.T. have been standardized from 110 to 120 V secondary winding voltage

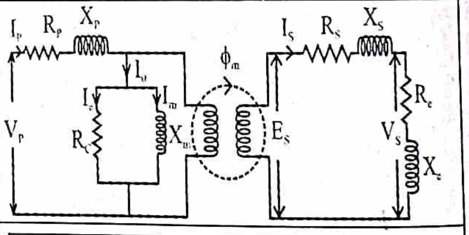
- **Ratio of Instrument Transformers-**

Transformation ratio (R)	**For C.T.** $R = \frac{\text{Primary winding current}}{\text{Secondary winding current}}$ **For P.T.** $R = \frac{\text{Primary winding voltage}}{\text{Secondary winding voltage}}$
Nominal Ratio (k_n)	**For C.T** $k_n = \frac{\text{Rated primary winding current}}{\text{Rated secondary winding current}}$ **For P.T.** $k_n = \frac{\text{Rated primary winding voltage}}{\text{Rated secondary winding voltage}}$
Turns Ratio (n)	**For C.T.** $n = \frac{\text{No. of turns of secondary winding}}{\text{No.of turns of primary winding}}$ **For P.T.** $n = \frac{\text{No. of turns of primary winding}}{\text{No.of turns of secondary winding}}$
Ratio Correction Factor (RCF)-	$RCF = \frac{\text{Transformation ratio}}{\text{Naminal ratio}} = \frac{R}{k_n}$

- **Burden of an Instrument Transformer-**

> ➢ It is convenient to express the load across the secondary winding terminals as the output in volt-ampere at the rated secondary winding voltage.
> ➢ It represents in VA unit.

- **Current Transformer-**

Circuit Diagram	 I_p R_p X_p I_0 I_c I_m V_p R_c X_m ϕ_m E_s I_s R_s X_s R_e V_s X_e
Transformation ratio	$R \simeq n + \frac{(I_m \sin\delta + I_e \cos\delta)}{I_S}$ $R \simeq n + \frac{I_e}{I_S} \simeq n\left(1 + \frac{I_e}{I_P}\right)$ $I_m = I_0 \cos\alpha, \quad I_e = I_0 \sin\alpha$
Phase angle	$\theta \simeq \frac{180}{\pi}\left(\frac{I_m \cos\delta - I_e \sin\delta}{nI_S}\right)$ degree $\theta \simeq \frac{180}{\pi}\frac{I_m}{I_P}$ degree

Ratio error	Ratio error $= \frac{\text{Nominal ratio}(k_n) - \text{Actual ratio}(R)}{\text{Actual ratio}(R)}$
Characteristics	• Effect of power factor of secondary burden on errors (a) ratio error (b) phase angle • Effect of change of primary current • Effect of change in secondary burden • Effect of change of frequency
Cause of error	• Due to magnetizing current (I_m) • Due to eddy and hysteresis loss • Due to saturation of core • Due to magnetic leakage
Reduction of errors	• Actual transformation ratio has to be close to the nominal ratio • Phase angle is to be small • I_e and I_m must be small as compared to I_p

- CT ratio error is dependent on eddy current loss and magnetizing current.

☞ Remember point

- In order to minimize errors, the core must have high permeability and low core loss.
- The phase angle error is effected very little by a change of one or two turns in the secondary.
- The secondary winding of the current transformer is always short circuit.
- The primary current of C.T. is depending on the load connected to system but it is does not depends on secondary winding burden.
- The secondary number of turns are reduced by 1 or 2 turns then the ratio error reduces.

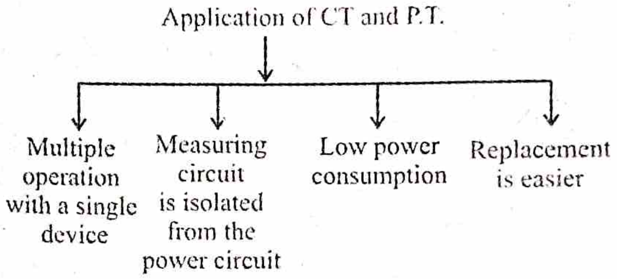
■ Potential Transformer

Actual transformation ratio	$\boxed{R = n + \frac{\frac{I_S}{n}[R_p \cos\delta + X_p \sin\delta] + I_e r_p + I_m X_p}{V_S}}$
Phase angle	$\boxed{\theta = \frac{I_S}{V_S}(X_S \cos\delta - R_S \sin\delta) + \frac{I_e X_p - I_m r_p}{nV_S} \text{rad.}}$
Characteristics	• Effect of secondary current or VA • Effect of power factor or secondary burden • Effect of frequency • Effect of primary voltage
Cause of error	• Ratio (voltage) error • Phase angle error

Reduction of error	• Reduction of magnetizing and loss component • Reduction of resistance and leakage reactance • Turns compensation

☞ Remember point

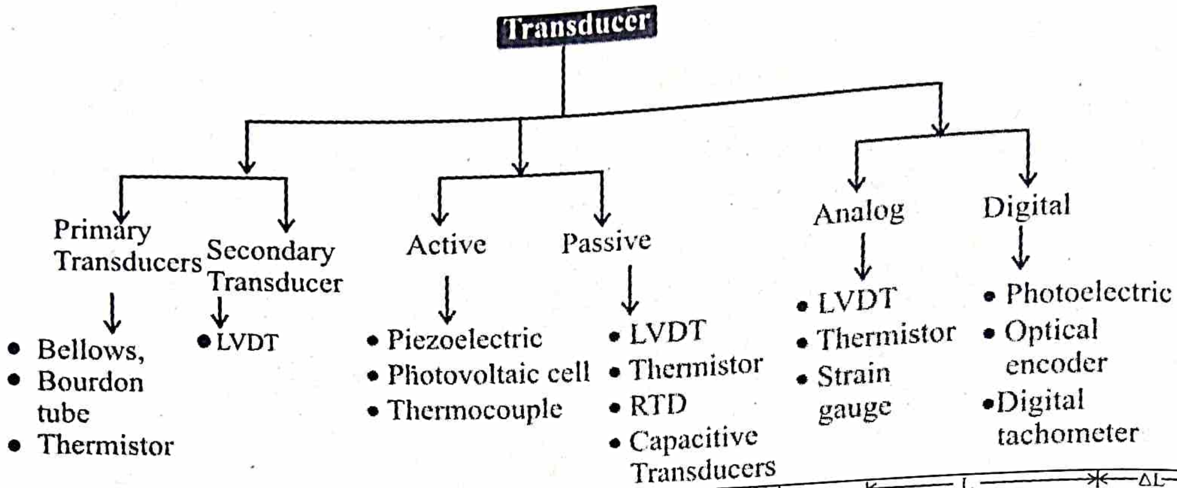
- C.T. never operates with secondary winding open but P.T. can be operated with secondary winding open.
- Strip wound core is used to reduce ratio error and phase angle error.


Application of CT and P.T.
Multiple operation with a single device
Measuring circuit is isolated from the power circuit
Low power consumption
Replacement is easier

Current Transformer	**Potential Transformer**
C.T. is used for high current measurement.	P.T. is used for high voltage measurement.
The flux density and exciting current (I_0) of a C.T. varies over a wide range.	The flux density and exciting current (I_0) of a P.T. varies over a restricted range.
Secondary winding of a C.T. should not be open circuited.	The secondary winding of a P.T. can be opened circuited.
A C.T. is equivalent to a series transformer operating under virtual short circuit condition	A P.T. is equivalent to a parallel transformer with its secondary winding operating under open circuit conditions.
The primary winding current of a C.T. is independent of the secondary winding circuit conditions.	The primary winding current of a P.T. is dependent upon the secondary circuit burdens.
In a C.T. a small voltage exists across its terminals.	In a P.T. a full voltage exists across its terminals.

☐ Transducer

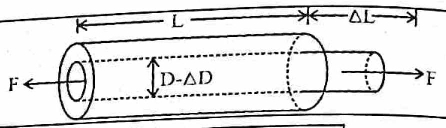
- Convert one form of energy into other form of energy
- Also called pickup


Transducer
Primary Transducers
Secondary Transducer
Active
Passive
Analog
Digital
• Bellows,
• Bourdon tube
• Thermistor
•LVDT
• Piezoelectric
• Photovoltaic cell
• Thermocouple
• LVDT
• Thermistor
• RTD
• Capacitive Transducers
• LVDT
• Thermistor
• Strain gauge
• Photoelectric
• Optical encoder
•Digital tachometer

- **Mechanical Primary Transducer Element**

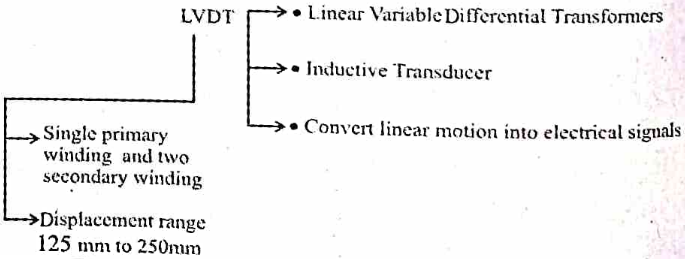
Type	Operation
A. Contacting spindle, pin or finger	Displacement to displacement
B. Elastic Member	
1. Proving ring	Force to displacement
2. Bourdon tube	Pressure to displacement
3. Bellows	Pressure to displacement
4. Diaphragm	Pressure to displacement
5. Spring	Force to displacement
C. Mass	
1. Seismic mass	Forcing function to displacement.
2. Pendulum scale	Force to displacement
3. Manometer	Pressure to displacement.
D. Thermal	
1. Thermocouple	Temperature to electric current.
2. Bimetallic	Temperature to displacement.
3. Thermistor	Temperature to change in resistance
E. Hydropneumatic	
1. Static	
(a) Float	Fluid level to displacement.
(b) Hydrometer	Specific gravity to displacement.
2. Dynamic	
(a) Orifice	Velocity to pressure.
(b) Venturi	Velocity to pressure.
(c) Pitot tube	Velocity to pressure
(d) Vanes	Velocity to force
(e) Turbines	Linear to angular velocity

- **Measurement of Displacement**
- **Strain Gauge-**

Measure	**Force to displacement**
Other name	**Piezo-resistive gauge**
Circuit Diagram	
Gauge factor	$\boxed{(G_f)=\frac{(\Delta R/R)}{(\Delta L/L)}=\frac{\Delta R/R}{\varepsilon}}$ $\boxed{\varepsilon = \text{strain} = \frac{\Delta L}{L}}$ $\boxed{G_f = 1+2\gamma}$
Poisson's ratio (γ)	$\gamma = \frac{\text{Lateral strain}}{\text{Longitudinal strain}} = \frac{-\Delta D/D}{\Delta L/L}$
Value of gauge factor	For metal (1.5 to 1.7) For semiconductor (More than 100)
Types	Bonded strain gauge Un-bonded strain gauge Thin foil strain gauge Thin film strain gauge Semiconductor strain gauge

- **Load cell -** Primary transducer + Strain gauge

■ Linear Variable Differential Transformer (LVDT)


LVDT
• Linear Variable Differential Transformers
• Inductive Transducer
• Convert linear motion into electrical signals
Single primary winding and two secondary winding
Displacement range 125 mm to 250mm

Property	Inductive transducer Passive transducer
Measure	Linear displacement into emf
Construction	Single primary winding and two secondary winding The secondary winding are connected in such a way that, the induced emf cancelled out each other.
Range	±0.01 mm to 25mm
Advantage	High sensitivity and used upto 25 kHz
Disadvantage	Sensitive to stray magnetic field Sensitive to mechanical vibration

Application	Used for primary transducer for the displacement measurement and as secondary transducer for force pressure measurement.

- Galvanometers

Types:

➢Tangent galvanometer ➢Astatic galvanometer

➢Mirror galvanometer ➢Ballistic galvanometer

D'Arsonval Galvanometer-

Measurement	Low current
Deflecting torque	$\boxed{T_d = BINA = GI}$
Controlling torque	$\boxed{T_C = K\theta_f}$
Final steady deflection	$\boxed{\theta_f = \left(\frac{NBA}{K}\right)I = \left(\frac{G}{K}\right)I}$ Where, B = Flux density (Wb/m^2) I = Current through moving coil(A) N = No. of turns in coil A = ℓ.d = Area of coil (m^2) G = Displacement constant of galvanometer
Types	• Suspended coil galvanometer • Pivoted coil or Weston galvanometer

- **Piezoelectric Transducer**

Property	It is active transducer and used to displacement acceleration force and pressure
Material	**Natural group-** Quartz and Rochelle salt **Synthetic group-** Barium titanate, potassium dihydrogen phosphate
Formula	Charge Sensitivity, $\boxed{d = \frac{Q}{F}}$ (C/N) Voltage Sensitivity, $\boxed{g = \frac{E}{P}}$ (V−m/N) Output Voltage $\boxed{E_0 = gtp}$ Q = Charge t = Thickness of crystal E = Electric field intensity P = Pressure applied
Advantage	• Self generating transducer • Good frequency response upto 20 kHz
Disadvantage	• Output voltage effect due to temperature variation.

- **Measurement of Temperature**

Transducer	**Measurement range (in °C)**
Resistance thermometer (RTD)	upto 600°C
Thermocouple	upto 1400°C
Thermistors	−100°C to 300°C
Pyrometer	1200°C to 3500°C
Bimetallic strip	Room temp. (27°C)

1. Resistance Temperature Detector (RTD)

<table>
<tr><td>Principle</td><td>Change in resistance in heating element</td></tr>
<tr><td>Range</td><td>– 200°C to 650°C</td></tr>
<tr><td>Formula</td><td>$\Delta R = \alpha \Delta T R_1$</td></tr>
<tr><td>Material</td><td><table>
<tr><td>Material</td><td>Temp.range</td><td>Accuracy</td></tr>
<tr><td>Platinum</td><td>upto 538°C</td><td>±0.5°C</td></tr>
<tr><td>Copper</td><td>upto 150°C</td><td>±0.2°C</td></tr>
<tr><td>Nickel</td><td>upto 316°C</td><td>±0.2°C</td></tr>
</table></td></tr>
<tr><td>Advantage</td><td>• Fast response, small size and low temperature.
• Compensation is not required</td></tr>
<tr><td>Disadvantage</td><td>• Bridge circuit needs a power supply.
• Cost is high.</td></tr>
</table>

2. Thermocouple

Principle	• Seebeck effect • It is an active transducer
Range	–270°C to 2800°C
Formula	$e = A\Delta T + B(\Delta T)^2$

ISA type designation	**+ve metal**	**–ve metal**	**Temperature Range**
T	Copper	Constantan	–250°C to 400°C
J	Iron	Constantan	–200°C to +850°C
B	Platinum Rhodium	Platinum	0 °C to 1400°C
E	Chromel	Constantan	–196 °C to 999 °C
K	Chromel	Alumel	–190 °C to 1371 °C
Y	Iron	Constantan	–129 °C to 982 °C

3. Thermistors

Property	• Negative temperature coefficient • **Temperature range-**100°C to 300°C • **Resistance range** – 0.5Ω to 0.75 MΩ • **Thermistors -** Thermal + Resistance
Formula	$\boxed{R_{T_1} = R_{T_2}\exp\left[\beta\left(\frac{1}{T_1} - \frac{1}{T_2}\right)\right]}$

Note :

I. Sensitivity- $S_{thermistor} > S_{RTD} > S_{thermocouple}$
II. Linearity- RTD>Thermocouple>Thermistor

Measurement of Pressure

Gauge	**Pressure range (mm of Hg)**
Low pressure measurement	
• Pirani gauge	10^{-1} to 10^{-3}
• Thermocouple vacuum gauge	upto 10^{-2}
• Mcleod gauge	$<10^{-4}$
• Thermistor vacuum gauge	2.6×10^{-3} to 1.3×10^{-2}
• Ionization type vacuum gauge	10^{-3} to 10^{-8}
High pressure Bridgman gauge	10^{5}ATM

- **Mechanical gauge for low pressure**

➢ Bourdon tube ➢ Bellow ➢ Diaphragms

- **Data acquisition system**

➢ It is a information system that collects, stores and distributes information.

➢ Data acquisition system are used to measures and record analog signals in basically to different ways.

(i) Signal which originate from direct measurement of electrical quantities

(ii) Signal which originate from use of transducer

- **Data acquisition system (Signal conditioning)-**

➢ Amplification
➢ Filtering
➢ Linearization
➢ Isolation
➢ Excitation

- **Types of Instrumentation Systems-**
- **Analog data acquisition system**

Measurement	The system deals with information in analog form
Components	1. Transducer 2. Signal conditioning equipment 3. Calibrating equipment 4. Integrating equipment 5. Visual display device 6. Analog recorders 7. Analog computers 8. High speed cameras and TV equipment
Use	When wide frequency width required are when lower accuracies can be tolerated.

- **Digital Data Acquisition System-**

Measure	A digital quantity make consists of a number of discrete or discontinuous form.
Component	1. Transducer 2. Signal conditioning equipment 3. Multiplexer
	4. Signal converter 5. Auxiliary equipment 6. Digital recorder 7. Digital printer
Use	When the physical quantities being monitor has a narrow bandwidth, high accuracy and low per channel cost is required.

❑ Telemetry System-

Telemetry is the indicating recording or integrating of a quantity at distance by electrical means. This may be voltage, current, position, frequency and pulse.

Classification of Telemetry System-

IEEE designation	**Short distance**	**Long distance**	**Analog**	**Digital**
Voltage	Yes	No	Yes	No
Current	Yes	No	Yes	No
Position	Yes	No	Yes	No
Frequency	Yes	Yes	Yes	No
Pulse	Yes	Yes	Yes	Yes

Measurement of Speed -

In industrial processes, a variable speed refers to the revolutions per minute of some piece of rotating equipment. There are various methods of measurement like tachometers are the most frequently used device.

- **There are the different types of electrical tachometers :**

➢ Eddy - current or magnetic drag-type tachometers.
➢ Electric generator tachometers, either a.c. or d.c.
➢ Contactless tachometers.
➢ Frequency tachometers.
➢ Ignition-type tachometers.
➢ Stroboscopic tachometers.

Tachometer Generators -

The tachometer generator is an electromechanical device which generates a voltage output proportional to shaft speed.

- **Types :**

(i) A.C. Tachometer
(ii) D.C. Tachometer

- **Contact less Tachometer (magnetic pickup sensors)-**

➢ This type of tachometer produces pulses from a rotating shaft without any mechanical contact.

$$\text{Output frequency (f)} = \frac{\text{rpm} \times \text{No. of gear teeth}}{60}$$

Range - 0 to 25 rpm to 0 to 72000 rpm

Accuracy - $\pm\frac{1}{2}\%$ full scale

Reproducibility = 0.2% full scale.

Basic Electrical Engineering

Transformer

- A transformer is a static device which transforms power from one side to other side without changing the frequency with the help of 'Faraday's law of electromagnetic induction'.
- Transformer is a bilateral, linear device.
- **There are generally two types of transformers-**
  (1) Core-type (2) Shell-type

Comparison between Core-type and Shell-type Transformer

Core-type	Shell-type
Cylindrical or Concentric type winding is used	Sandwich or Disc type winding is used
Has only one magnetic flux path.	Have two magnetic flux paths.
Preferred for high rating of large transformer.	Preferred for low rating of small transformer.
Called as series magnetic circuit.	Called as parallel magnetic circuit.
Its outer winding has H.V. (High Voltage)	Its outer winding has L.V. (Low Voltage)
Used strips are, L-L/U-I	Used strips are, E-I/U-T
Voltage regulation of core type transformer is poor than Shell-type transformer.	Voltage regulation of shell type transformer is better than Core-type transformer.

Comparison between 'Power transformer' and 'Distribution transformer'

Power Transformer	Distribution Transformer
Voltage may be step up or step down.	Voltage is always step down.
Indoor located	Outdoor located
Used for transmission and generating station	Used to distribute the power near to load
Its capacity is in MVA	Its capacity is in kVA
Designed for maximum efficiency at near by 100% load.	Designed for maximum efficiency at 50 to 75% load
Tap changer not uses	Tap changer used only for distribution.
Copper loss minimum	Iron loss minimum

Important components of a Transformer :

- **Winding**
- In transformer there are two windings are used, which are primary and secondary

Remember Point

H.V. Winding- It has large number of turns of thin wire.

L.V. Winding- It has less number of turns of thick wire.

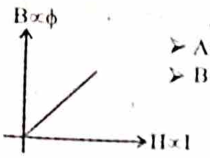
- **Breather -**
- When the load on the transformer decreased then transformer takes breath so, breather is used to filter out the moisture content from the air.
- It is connected with conservator tank.
- **Silica gel -**
- Silica gel is used in breather to absorbs the moisture content.
- Colour of silica gel is blue at good condition and it becomes violet then pink as it absorb moisture.
- **Buchholz relay -**
- It is used to protect the transformer from the internal faults, like-short circuit, inter-turns fault and insulation failure
- It is gas operated relay.
- It is used only for oil filled transformer.
- It is connected between main tank and conservator tank.
- It is used for the transformer of 500 kVA and above for oil filled transformer.

Note – CT → Step up transformer
PT → Step down transformer

- **Transformer oil-**Mineral and synthetic oil used as transformer oil. It is used to provides insulation and cooling purposes and dielectric strength of transformer oil is 33 kV/mm.
- **Transformer oil should have.**
  i. Low viscosity ii. Low volatility
  iii. High flash point (140^{0}C)
  iv. Low pour point (–30^{0}C to–40^{0}C)
- **Ideal transformer-**
  The transformer which is free from all types of losses is known as an ideal transformer.
- **Practical transformer-**
  The practical transformer has some winding resistance, some leakage flux, so there are a little-bit losses.
- **Humming noise-**
- Noise in transformer is called as 'humming noise'.
- Humming comes due to 'magnetostriction'.
- **All day efficiency-**
- It is used for distribution transformer.
- All day efficiency

$$= \frac{\text{Energy output in kWh for 24 hour}}{\text{Energy input in kWh for 24 hour}}$$

- **Air core transformer-**
- If core of transformer is replaced by air then transformer is called as air core transformer.



- Area under B-H curve is zero
- B-H curve is linear

- **Isolation transformer-**
  - It is used to isolate the power circuit and control circuit.
  - It is used in electronic circuit for impedance matching.
  - The turns ratio of isolation transformer is 1:1
- **Transformation ratio (K) -**

$$\boxed{\frac{E_2}{E_1} = \frac{N_2}{N_1} = \frac{I_1}{I_2} = K}$$

K = 1, For isolation T/F

K >1, For step up T/F

K < 1, For step down T/F

- **Transformer turn ratio (A) -**

$$\boxed{\frac{E_1}{E_2} = \frac{N_1}{N_2} = \frac{I_2}{I_1} = A}$$

- **EMF Equation of transformer**
  RMS value -

(1) $\boxed{E_1 = 4.44\phi_m f N_1}$ (2) $\boxed{E_2 = 4.44\phi_m f N_2}$

- **Average value -**

(1) $\boxed{E_1 = 4\ \phi_m f N_1}$ (2) $\boxed{E_2 = 4\ \phi_m f N_2}$

- **Losses in transformer –**

Core loss	Copper loss
It is called as a constant losses	It is called as a variable losses
Core losses = $P_e + P_h$ P_e = Eddy current loss P_h = Hysteresis loss	Copper losses = $I_1^2R_1 + I_2^2R_2$

- **Comparison between Eddy current loss and Hysteresis loss -**

Comparative factor	Eddy current loss	Hysteresis loss
Definition	Loop of electric current is induced in conductor by changing the magnetic field in the conductor	It occurs because of the reversal of the magnetism.
Formula	$P_e = k_e B_m^2 f^2 t^2 V$ Where, B_m = Maximum flux density V = Volume of core f = Supply frequency t = Thickness of core	$P_h = k_h B_m^{1.6} f.V$ Where, B_m = Maximum flux density V = Volume of core f = Supply frequency
Minimizing method	By making the core of thin lamination.	By using silicon steel material.

- **Dependency of iron loss and copper loss at different load -**
  - Iron losses remains always constant at any load but copper losses changes according to load.
  - Copper loss at any load $\boxed{(P_{cu}) = x^2 .\ P_{cu(f\ell)}}$

Where,

x → Load condition ratio

$P_{cu(f\ell)}$ → Copper loss at full load

Remember Point-

- No-load current of a practical transformer is 3-5% of full load current.
- No-load power factor is small due to large magnetizing current
- Power factor at no-load is 0.2 – 0.3
- No-load power $(P_0) = V_1 I_0 \cos\phi_0$

- **Condition for maximum efficiency-**
  Core loss = Copper loss i.e. $[P_i = P_{cu}]$

$$\boxed{\text{Rated kVA} = \text{Full load kVA}\sqrt{\frac{P_i}{P_{cu}}}}$$

- **Voltage Regulation-**

$$\boxed{V.R. = \frac{V_{n\ell} - V_{f\ell}}{V_{n\ell}}}$$

Where, $(V_{n\ell} - V_{f\ell})$ → Voltage drop

$V_{n\ell}$ → No load voltage

$$\boxed{\% V.R. = \frac{I_2R_2\cos\phi_2 \pm I_2X_2\sin\phi_2}{E_2}}$$

$$\boxed{V.R. = R_{P.U.}\cos\phi_2 \pm X_{P.U.}\sin\phi_2}$$

Where,

(+ve) sign for lagging P.F.

(−ve) sign for leading P.F.

- **Condition for zero voltage regulation-**

$$\boxed{\tan\phi = \frac{-V_r}{V_x} = \frac{-R_2}{X_2}}$$

- **Condition for maximum voltage regulation-**

$$\boxed{\tan\phi = \frac{V_x}{V_r} = \frac{X_2}{R_2}}$$

- **Testing of Transformer**

Open circuit test	**Short circuit test**
Used to find core losses	Used to find copper losses
Used to find shunt branch parameters (R_0, X_0)	Used to find series branch parameters (R_{01}, X_{01})
It is performed at L.V. side at rated voltage and rated frequency.	It is performed at H.V. side at rated voltage (5–10%) rated current and rated frequency
Instruments are connected at L.V. side	Instrument are connected at H.V. side.

- **Sumpner test/Back to back test/Heat and run test** –

➢ By this test total heat developed in transformer due to core loss and copper loss can be calculated.

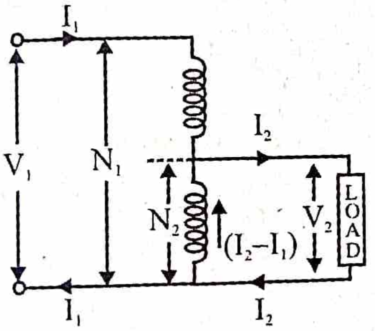
➢ Two identical transformers are connected back to back.

➢ Used to find efficiency and temperature rise of transformer.

- **Efficiency of Transformer -**

$$\boxed{\eta = \frac{V_2 I_2 \cos\phi_2}{V_2 I_2 \cos\phi_2 + P_i + P_{cu}}}$$

- **Auto transformer -**



➢ It is a single winding transformer

➢ Winding is connected inductively as well as conductively

➢ Used for variable voltage

➢ Total transfer power = Inductively transfer power + Conductively transfer power

➢ Inductively transfer power = (1–K). Input power

➢ Conductively transfer power = K. Input power

Where,

K = Transformation ratio of auto T/F

$$\boxed{K = \frac{L.V.}{H.V.} = \frac{V_2}{V_1} = \frac{E_2}{E_1} = \frac{N_2}{N_1} = \frac{I_1}{I_2}}$$

- **Advantage of auto transformer -**

➢ It has lower losses and high efficiency in comparison two winding transformer.

➢ Due to low value of per unit impedance voltage regulation of auto transformer is better than two winding transformer.

- **Disadvantage of auto transformer -**

➢ Since the primary and secondary of auto transformer is electrically connected it means there is no electrical isolation. Therefore any disturbance on any one side may split to another side.

- **Open delta connection (V-V Connection) -**

➢ Used when one bank of transformer is damaged.

$$\boxed{V-V\,\text{rating} = 57.7\%\,\text{of}\,\Delta-\Delta}$$

- **Scott connection (T-T connection) -**

➢ Used to convert 3-ϕ to 2-ϕ and vice-versa.

➢ It is used in electric furnace.

➢ It is used in electric traction system.

➢ Scott connection of transformer is called as T-T connection.

- **Parallel operation of Transformer -**

Must condition -

➢ Same polarity

➢ Same phase sequence

➢ Same voltage ratio

➢ The vector grouping must be same

- **Desirable condition -**

➢ Same X/R ratio for same power factor operation.

➢ Same kVA rating.

- **Transformer Cooling methods-**

➢ Oil Natural Air Natural (ONAN) Cooling – 250 kVA

➢ Oil Natural Air Forced (ONAF) Cooling – 5 MVA

➢ Oil Forced Air Forced (OFAF) Cooling- Up to 20 MVA

➢ Oil Forced Water Forced (OFWF) Cooling – Up to 63 MVA

- **Dry type Transformer –**

➢ 1000 kVA rating

➢ Rectifier transformer is water cooled.

❑ DC Machine

■ Construction of DC Machine

➢ Same for both DC motor and DC generator.

Main Parts

Stator	Rotor
• It is the outer part of DC machine. • It contains pole core, pole core has pole shoe, which are laminated • Pole core contains field winding	• It is the inner part of DC machine. • It has armature core and armature winding. • Armature core is made of laminated silicon steel.

Types of Armature winding of a DC machine-

Lap Winding	Wave winding
It is a complete winding so, mechanically balanced.	It is incomplete winding so, mechanically unbalanced. To make it balance, a 'Dummy coil' is used
Number of parallel path is equal to number of pole. $\boxed{A = P}$	Number of parallel path is always equal to two. $\boxed{A = 2}$
The additional coil used in the lap winding is Equalizer ring to stop circulating current	The additional coil used in the wave winding is Dummy coil to make mechanically balanced.
Lap winding used for → Low voltage and High current.	Wave winding used for → High voltage and Low current
Also called → Parallel winding or Multiple winding.	Also called → Series winding or Two-circuit winding.
Types → Simplex and Duplex	Types→ Progressive and Retrogressive
Efficiency → Less	Efficiency → High

Comparison between DC Generator and DC Motor

DC Generator	DC Motor
It converts mechanical energy into electrical energy.	It converts electrical energy into mechanical energy.
Direction of induced emf is find out by → Fleming's right hand rule.	Direction of rotation is find out by → Fleming's left hand rule.
Rating → kW	Rating → H.P.
It generates EMF which is- $E_g = \frac{P\phi ZN}{60A} = K\phi N$ Where, $K = \frac{PZ}{60A}$ = Constant	It produces torque which is $T = \frac{P\phi ZI_a}{2\pi A} = K\phi I_a$ Where, $K = \frac{PZ}{2\pi A}$ = Constant
'Voltage controlled' phenomena is used.	'Speed controlled' phenomena is used.

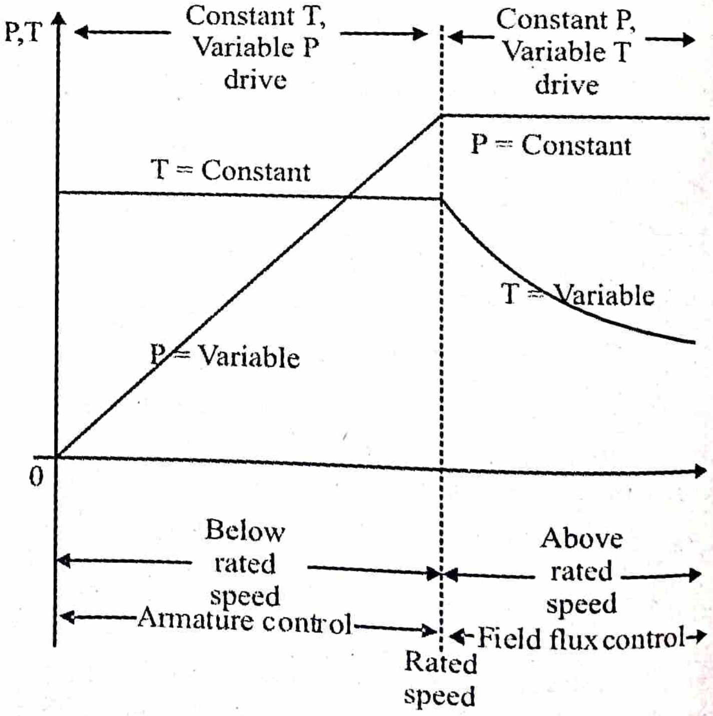
Some Important Formulas for DC Machine -

Formulas for DC Generator	Formulas for DC Motor
$E_g = \frac{\phi PNZ}{60A}$	$E_b = \frac{\phi PNZ}{60A} = K\phi N$
Load current $(I_L) = \sqrt{\frac{\text{Constant loss}(W_c)}{\text{Armature Resistance}(R_a)}}$	$T = \frac{P\phi ZI_a}{2\pi A} = K\phi I_a$
$E_g = V_T + I_aR_a$	$E_b = V_T - I_aR_a$
Prime mover output = Generator output + Total losses	Driving power = Output power + Stray losses
Electrical power produce in armature $(P) = E_g.I_a$	Driving power $= E_b.I_a$
Efficiency = $\frac{\text{Output}(\text{Electrical power})}{\text{Input}(\text{Mechanical power})}$	Efficiency = $\frac{\text{Output}(\text{Mechanical power})}{\text{Input}(\text{Electrical power})}$
Voltage Regulation = $\frac{V_{n\ell} - V_{f\ell}}{V_{f\ell}}$	Speed regulation = $\frac{N_{n\ell} - N_{f\ell}}{N_{f\ell}}$

Characteristics of DC Generator -

Characteristics	Relation	Known as
Open circuit characteristics	E_g / I_f	Magnetic characteristics
Internal characteristics	E_g / I_a	Total characteristics
External characteristics	V_T / I_L	Load characteristics

- **Power and Torque versus Speed characteristics**



- **Condition for maximum output power of generator-**

$$\boxed{V = \frac{E_g}{2}}$$

- **Condition for maximum developed mechanical power of motor** - $\boxed{E_b = \frac{V}{2}}$

> At maximum mechanical power develop condition, efficiency (η) will be less than 50%.

- **Relation between back emf and rotor speed of DC motor** - $\boxed{\frac{E_{b_2}}{E_{b_1}} = \frac{\phi_2 N_2}{\phi_1 N_1}}$

- **Relation between speed & torque of parallel and series connection** -

$$\boxed{N_{parallel} = 4N_{series}} \qquad \boxed{T_{parallel} = \frac{T_{series}}{4}}$$

Test	For determination of
Swinburne's test (No-load test)	Constant losses
Retardation test (Running down test)	Stray losses in case of DC shunt machine
Hopkinson test (Full load test) or Back-to-Back test or Regenerative test or Heat-run test	Used for the testing the efficiency of DC machine. Performance of machines regarding commutation and temperature rise.
Field test (for series motor)	Stray losses in case of DC series machine
Brake test (load test)	The efficiency of small motors.
Open circuit test	Core losses
Short circuit test	Copper losses

Type of starter -

Starter	Used
• Two-point starter	Only for DC series motor
• Three-point starter	For DC shunt motor and DC compound motor
• Four-point starter	To start and control the speed of a DC shunt motor with field weakening control.

- **Armature Reaction -**

> The effect of armature flux on the main field flux is known as armature reaction.

- **Essential condition for voltage build up in DC generator -**

> Shunt field resistance (R_{sh}) < Critical resistance (R_c)
> Rotor speed (N_r) > Critical speed (N_c)

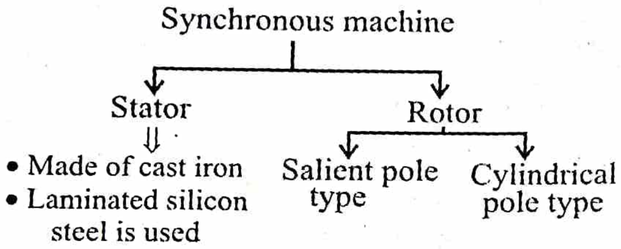
Application of DC Machine -

DC Generator Application	DC motor application
DC Shunt Generator- ➤ Used where constant voltage is required. ➤ As a battery charger ➤ As an exciter ➤ As power supply ➤ For electro plating	**DC Shunt Motor** Used where speed is fairly constant and requires medium starting torque ➤ Lathe machines ➤ Blowers and Fans. ➤ Milling machine ➤ Drilling machine ➤ Machine tools ➤ Centrifugal and Reciprocating pumps
DC Series Generator ➤ Used as a booster ➤ Uses as a supply for arc lamps. ➤ Used for series arc lighting	**DC Series Motor-** Used where high starting torque requires and no-load condition is dangerous at variable speed. • Crane • Hoist • Elevators • Trolleys • Conveyors • Electric locomotive
DC compound Generator Differential Compound Generator ➤ Used to supply dc welding machine Level Compound Generator ➤ Used to supply power for offices etc Over Compound Generator ➤ Used to Compensate the voltage drop in feeder	**DC Compound Motor** Cumulative Compound Motor Used in - • Elevator • Punches • Shears • Rolling mills Differential Compound Motor • Not suitable for any practical application

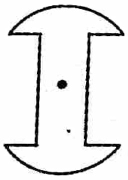
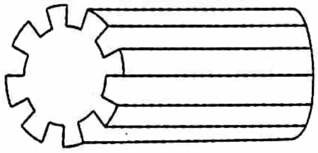
Characteristics of DC Motor

- Torque - Current characteristics. (T / I_a)
- Speed - Torque characteristics. (N / T)
- Speed- Current characteristics. (N / I_a)
- Shunt motor has best speed regulation
- Series motor has highest speed regulation.
- Differential compound motor has negative speed regulation.

Synchronous Machine



- **Rotor**

Salient Pole Type	Cylindrical Pole Type
	
Practically 12-20 poles are used	Practically 2 poles are used.
Large diameter and small axial length	Small diameter and large axial length
Air gap - Non-uniform	Air gap → Uniform
More noise and more mechanical loss	Low noise and low mechanical loss.
Synchronising capacity - Low	Synchronising capacity- High
Preferred for low speed alternators Ex- Used in Hydro Power Plant	Preferred for high speed alternators Ex- Used in Thermal Power plant.

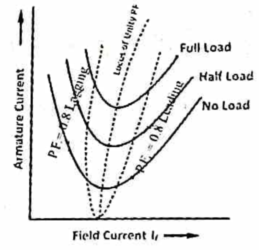
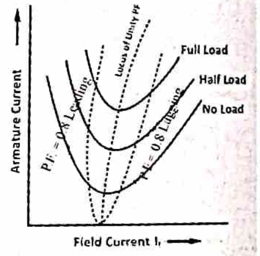
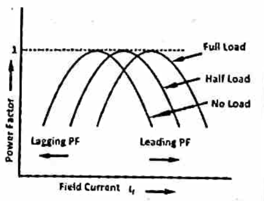
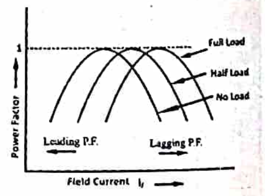
- **Armature Reaction :-**

Power Factor	Alternator	Synchronous motor
Unity	Entirely Cross-magnetizing	Entirely Cross-magnetizing
Zero (lag)	Completely De-magnetizing	Completely Magnetizing
Zero(lead)	Completely Magnetizing	Completely De-magnetizing
0.8 (lag)	Partly De-magnetizing + Partly Cross magnetizing	Partly magnetizing + Partly Cross magnetizing
0.8 (lead)	Partly Magnetizing + Partly Cross magnetizing	Partly De-magnetizing + Partly Cross magnetizing

- **Comparison between DC Generator and Alternator -**

DC Generator	Alternator
• It has rotating armature and stationary field • Generally large in size • Has lower output rating	• It has rotating field and stationary armature. • Generally small in size • Has higher output rating

- **V-curve and Inverted V-curve (Λ -curve) :-**
- **V-curve** – It draws between field current (I_f) and armature current (I_a)
- **Inverted V-curve**- It draws between field current (I_f) and P.F. (cos ϕ).

Curve	Synchronous motor	Alternator
V-Curve [It draw between (I_f/I_a)]		
Inverted V-Curve [It draw between ($I_f/\cos\phi$)]		

- **Comparison between 3-ϕ Induction motor and Synchronous motor -**

3-ϕ Induction Motor	Synchronous Motor
• Self started • Operates at lagging P.F. only. • Runs always less then synchronous speed • Singly excited motor	• Not self started • Operates at leading, lagging and unity P.F. • Runs always at synchronous speed • Doubly excited motor

Alternator	Synchronous Motor
(i) EMF equation of alternator - $\boxed{E = 4.44 K_w \phi f T_p}$ or $\boxed{E = 4.44 K_p K_d \phi f T_p}$ Where, K_W = Winding factor $K_W = K_p K_d$, K_P = Pitch factor, K_d = Distribution factor, f = Frequency of induced emf ϕ = Useful flux per pole T_P = Turn per phase **Application -** ➢Used to deliver 3-ϕ Power supply in power system	**(i) Torque equation for Synchronous motor -** $\boxed{T = \frac{3V_tE_f}{\omega_s . X_s} \sin\delta}$ Where, V_t = Terminal voltage, δ = Torque angle E_f = Excitation voltage, X_s = Synchronous Reactance $\frac{3}{\omega_s}$ = Constant **Application -** ➢ Used for constant speed that means for synchronous speed only. ➢ Used for power factor correction.

- **Voltage Regulation in Alternator-**

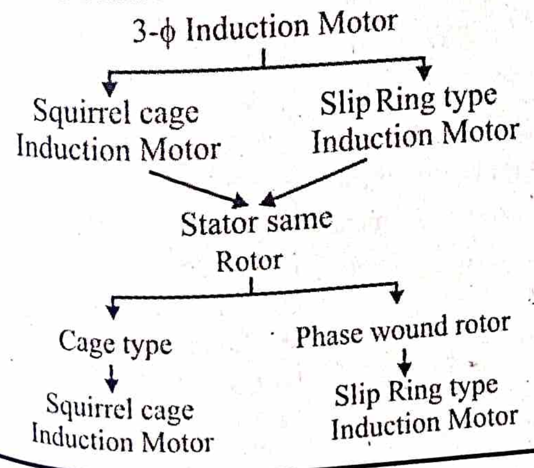
$$\boxed{V.R. = \frac{V_{n\ell} - V_{f\ell}}{V_{f\ell}}}$$

For **maximum voltage regulation -**	**For minimum voltage Regulation -**
$\boxed{\tan\phi = \frac{X}{R}}$	$\boxed{\tan\phi = \frac{-R}{X}}$

- **Method of voltage Regulation -**

EMF Method or Synchronous Impedance Method	The value of voltage regulation measured in this method is greater than actual value. It is also known as 'Pessimistic method'.
MMF method or Ampere-Turn method	The value of voltage regulation measured in this method is less than actual value. It is also known as 'Optimistic method'.
Zero-Power Factor method or Potier triangle method	The value of voltage regulation measured in this method is acceptable that means 'most accurately'. It is also known as 'Potier triangle method'.

Three Phase Induction Motor (3-ϕ I.M.)


3-ϕ Induction Motor
Squirrel cage Induction Motor
Slip Ring type Induction Motor
Stator same
Rotor
Cage type
Phase wound rotor
Squirrel cage Induction Motor
Slip Ring type Induction Motor

Comparison between Squirrel cage and Slip-Ring Induction Motor-

Squirrel cage Induction Motor	Slip-Ring Induction Motor
Rotor consists of bars which are shorted at the ends with the help of end rings.	Rotor consists of 3-ϕ winding.
It is permanently shorted and external resistance can't be added	Resistance can be added externally.
Starting torque → Low Running torque → High	Starting torque → High Running torque → Low
Almost 95% I.M. uses this type of rotor	Only 5% of I.M. are industry uses this type of rotor
Application- Drilling machine, Water pump Grinder, Lathe machine	**Application-** Lift, Hoist, Crain, Elevator

- **Relative speed between-**

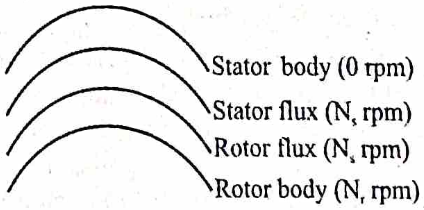
➢ Stator flux & Stator body → $(N_s - 0) = N_s$ rpm

➢ Stator flux & Rotor flux → $(N_s - N_s) = 0$ rpm

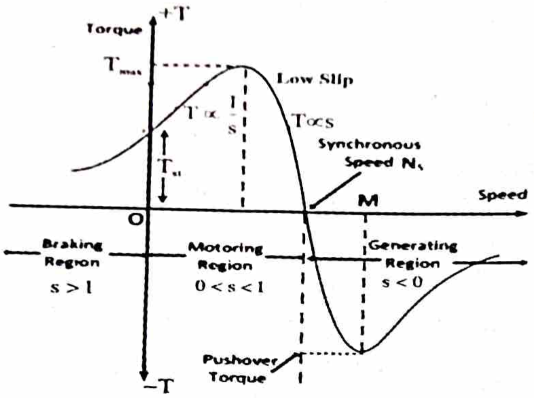
➢ Rotor flux & Rotor body → $(N_s - N_r)$ rpm

➢ Rotor body & Stator body → $(N_r - 0) = N_r$ rpm

➢ Stator flux & Rotor body → $(N_s - N_r)$ rpm


Stator body (0 rpm)
Stator flux (Ns rpm)
Rotor flux (Ns rpm)
Rotor body (Nr rpm)

- **Torque-Slip characteristics of 3-ϕ I.M.-**

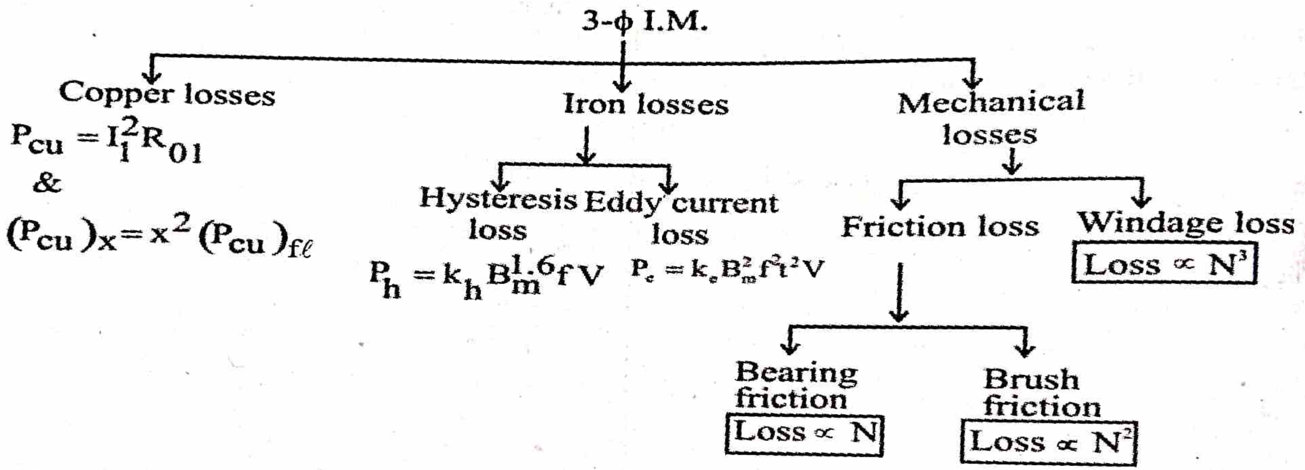


➢ In braking region value of slip is greater than 1.

➢ In motoring region value of slip is greater than zero but less than 1.

➢ In generating region value of slip less than zero.

- **Losses in 3-ϕ induction motor -**


3-ϕ I.M.
Copper losses
$P_{cu} = I_1^2 R_{01}$
&
$(P_{cu})_x = x^2 (P_{cu})_{f\ell}$
Iron losses
Hysteresis loss
$P_h = k_h B_m^{1.6} f V$
Eddy current loss
$P_e = k_e B_m^2 f^2 t^2 V$
Mechanical losses
Friction loss
Windage loss
$\boxed{\text{Loss} \propto N^3}$
Bearing friction
$\boxed{\text{Loss} \propto N}$
Brush friction
$\boxed{\text{Loss} \propto N^2}$

- **Testing of 3-ϕ Induction motor -**

No-load test	Block rotor test
It is similar to transformer's 'open circuit test'.	It is similar to transformer's 'short circuit test'.
Used to calculate iron losses.	Used to calculate copper losses.
Used to find shunt branch parameter, [R_0 & X_0]	Used to find series branch parameter. [R_{01} & X_{01}]

- **Crawling and Cogging in 3-ϕ induction motor-**
- **Crawling** – It comes due to harmonic (space harmonics) developed in the motor.

➢ To reduce crawling 'skewed rotor slot' is used.

- **Cogging-** Cogging occurs when the number of stator slots are equal to the number of rotor slots.

➢ To reduce the cogging, the number of stator slots should never be equal to that of rotor slots.

- **Circle diagram-**

➢ The circle diagram provides information about the power output, power factor, torque, speed, losses and the efficiency of the induction motor.

➢ Frequency can not be determined.

- **Speed control of 3-ϕ Induction motor-**

Slip control method	Synchronous speed control method
• $\boxed{T \propto \frac{sV^2}{R}}$ • Voltage control method • Rotor resistance method • Rotor EMF injection method	• $\boxed{N_s = \frac{120f}{P}}$ and $\boxed{N_r = N_s(1-s)}$ • Frequency control method • Pole changing method' • Cascading of 2 induction motor.

- **Type of starter used in 3-ϕ Induction motor-**

For Squirrel cage I.M.	For Slip ring I.M.
Direct on-line starter (DOL) (used upto →5H.P) Star-Delta starter (used upto →20H.P.) Auto transformer starter (used above→ 20 H.P.)	Rotor resistance starter Injected slip frequency emf in the rotor.

- **Most important formula for 3-ϕ Induction motor-**

➢ $\text{Torque}(T) = \dfrac{sKE_2^2R_2}{R_2^2+(sX_2)^2}$

- **At starting condition -**

At starting, slip (s) = 1

➢ $\text{Starting torque } (T_{st}) = \dfrac{KE_2^2R_2}{R_2^2+X_2^2}$

- **Condition for maximum torque -**

➢ $T_{max} = \dfrac{KE_2^2}{2X_2}$, ➢ $s_{max} = \dfrac{R_2}{X_2}$

- **Relation between rotor input, rotor copper loss and rotor output-**

➢ $P_g : P_{cu} : P_o = 1 : s : (1-s)$

➢ $\text{Slip (s)} = \dfrac{N_s - N_r}{N_s}$ ➢ $N_r = N_s(1-s)$

➢ $\text{Synchronous speed } (N_s) = \dfrac{120f}{P}$, Slip speed $= N_s - N_r$

- **Ratio of Torque-**

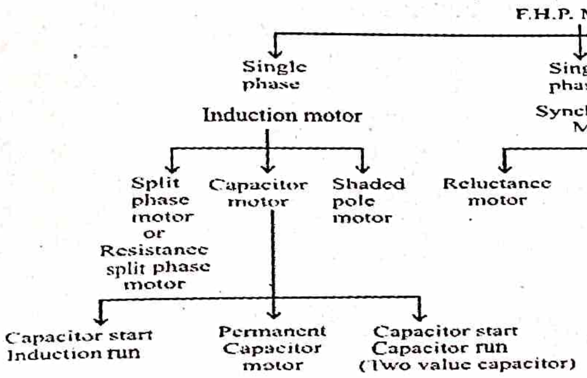
(When stator impedance and magnetizing reactance are neglected)

$$\boxed{\frac{T_{f\ell}}{T_{max}} = \frac{2s_{f\ell}.s_m}{s_{f\ell}^2+s_m^2}}, \boxed{\frac{T_{st}}{T_{max}} = \frac{2s_m}{s_m^2+1}}, \boxed{\frac{T_{st}}{T_{f\ell}} = \frac{s_{f\ell}^2+s_m^2}{(s_m^2+1).s_{f\ell}}}$$

- **Starting of 3-ϕ Induction motor-**

Starter	Ratio
1. DOL starter (Direct online starter)	$\dfrac{T_{st}}{T_{f\ell}} = \left(\dfrac{I_{st}}{I_{f\ell}}\right)^2 .s_{f\ell}$
2. Star-Delta starter	$\dfrac{T_{st}}{T_{f\ell}} = \dfrac{1}{3}\left(\dfrac{I_{st}}{I_{f\ell}}\right)^2 .s_{f\ell} = \dfrac{1}{3}\text{ DOL}$
3. Auto-Transformer starter	$\dfrac{T_{st}}{T_{f\ell}} = x^2\left(\dfrac{I_{st}}{I_{f\ell}}\right)^2 .s_{f\ell} = x^2\text{ DOL}$

- **Single Phase Motor or Fractional Horse Power (F.H.P.) Motor -**


F.H.P. Motor
Single phase Induction motor
Single phase Synchronous Motor
Single phase Commutator motor
Split phase motor or Resistance split phase motor
Capacitor motor
Shaded pole motor
Reluctance motor
Hysteresis motor
Repulsion motor
Universal motor
Capacitor start Induction run
Permanent Capacitor motor
Capacitor start Capacitor run (Two value capacitor)

- **Comparison between 1-ϕ and 3-ϕ Induction motor-**

Parameter	1- ϕ I.M.	3-ϕ I.M.
Starting	Not self started	Self started
Size	Large	Small
Slip	Forward & Back ward slip	Only forward slip
Direction of reversal of rotation	By charging either main or auxiliary winding	By changing any two phase sequences
Auxiliary winding	Requires	Not requires.
Winding	Concentrated	Distributed
Temperature	More temperature rise	Low temperature rise
Application	Domestic use	Industrial use.

- **Double revolving field Theory-**

➢ $\text{Forward slip } (s_f) = \dfrac{N_s - N_r}{N_s} = s$

➢ Backward slip (s_b)

$$= \frac{N_s-(-N_r)}{N_s} = \frac{N_s+N_r}{N_s} = (2-s)$$

➢ Hence, $s_f + s_b = s + (2-s) = 2$, $\boxed{s_f + s_b = 2}$

$\boxed{s_f = 2 - s_b}$ $\boxed{s_b = 2 - s_f}$

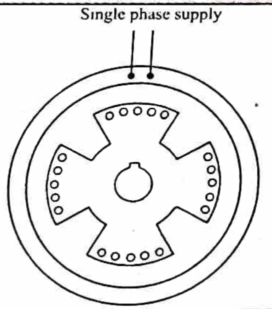
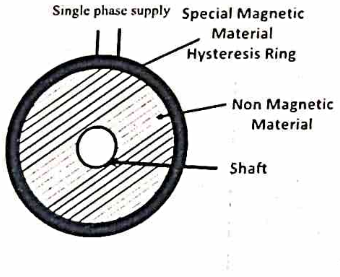
Application of 1-ϕ I.M.

1− ϕ I.M.	Application
Split phase or Resistance start	• Washing machine • Fans • Blowers • Centrifugal pumps • Refrigerators • Oil burners and various other low starting torque applications.
Capacitor start induction run motor	• Refrigerator • Compressor • Conveyer •Pumps Air conditioner or other application involving a high starting torque application.
Permanent capacitor motor	• Ceiling Fans • Blowers • Oil burners and they are also use to drive office machinery because the permanent capacitor motor are silent in operation.
Capacitor start & Capacitor run motor	• Air compressor • Refrigerator • Conveyors • Small lathes • Pumps This motor used when an extremely high starting torque is required.
Shaded pole motor	The starting torque of shaded pole motor is very small. It is used for. Small fans. • Hair dryers• Toys • Time phonographs. Etc.

Shaded pole 1-ϕ motor-

- ➢ It rotates from unshaded to shaded
- ➢ Efficiency→ 5–35%
- ➢ Its direction of rotation can not be changed.
- ➢ Used where least torque is required.

Single phase synchronous motor-

Reluctance motor	Hysteresis motor
	 Single phase supply Special Magnetic Material Hysteresis Ring Non Magnetic Material Shaft
Stator- It has laminated construction made up of stampings. **Rotor-** Same as salient pole and not have any winding. • At starting it runs at sub-synchronous speed and at steady state it runs at synchronous speed. **Application-** • Recording instrument • Signaling devices	**Stator-** Its stator is designed to produce a synchronously revolving field from a 1-ϕ supply. **Rotor-** It is made up of hard chrome steel without winding and teeth. • At starting it starts with eddy current and hysteresis both but at running condition it runs only with hysteresis loss. **Application-** • Timing device
• Timers	• Recording player • Tap recorder and sound producing equipment • Electric clock

Single phase commutator motor-

Repulsion motor	Universal motor
• It works on the combined principle of repulsion and induction • It has high starting torque. • It has lap and wave both type of winding **Application-** • Electrical locomotives • Printing press • Vacuum cleaner • Hoist	• It works on both AC and DC supply • Also known as 1-ϕ series motor. • It has high starting torque and variable speed characteristics. **Application-** • All kitchen appliance ex- mixture, grinder • Electric shaver • Vacuum cleaner • Portable tools • Drilling machine.

Special purpose motor-

Stepper motor	Servo motor
• Digital to Analog converter. • Constant power device • It has no brushes, winding and commutator on rotor. **Application-** • Small robotics • Digital watches • X-Y plotter • Computer printing device • Process control system	• It consists of electric motor, feedback device and electronic controller. • Used an encoder. **Application-** • Radar • Robotics • Computers • Toys • CD/DVD Player •DC servo motor → High power use •AC servo motor → Low power use

Note:

$$\text{Step angle } (\beta) = \frac{\text{Total revolution}}{\text{Number of steps}} \times 360^\circ$$

$$\beta = \frac{N_s - N_r}{N_s . N_r} \times 360^\circ$$

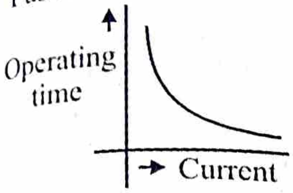
Comparison between AC motor and DC motor

AC motor	DC motor
AC Motor can be single phase or three phase	All DC motor are single phase
Generates more heat comparatively to dc motor	Generates less heat, hence less energy is wasted
In AC motor Armature do not rotate while magnetic field continuously rotates	In DC motor the armature rotates while magnetic field does not rotate
AC motor requires on effectives starting equipment like capacitor to start operation	DC motor do not require any external help to start operation

Average starting Torque	Very high starting Torque
Easy to install	Complicated to install
Repairing of AC motors are not costly	Repairing of DC motor are costly

❑ Fuse

- ➢ Fuse is a device used in circuit for protecting electrical equipment against overload and short circuit.
- ➢ Fuse have inverse time characteristics.



$$\boxed{I = kd^{3/2}}$$

Where, k= Fuse constant.
I = Minimum fusing current
d = Diameter of the fuse element

- **Fusing current depends on following factor -**
- ➢ Material of fuse element.
- ➢ Length of the fuse element.
- ➢ Diameter of the fuse element.
- ➢ Size and location of the terminals.
- **Fusing Factor**
- ➢ Fuse rating < Minimum fusing current
- ➢ Fusing factor = $\dfrac{\text{Minimum fusing current}}{\text{Fuse rating}} > 1$
- ➢ Its value is greater than 1.
- ➢ For copper wire the value of fusing factor is 2.
- ➢ For HRC fuse the value of fusing factor is 1.25.
- ➢ Total operating time -

$$\boxed{T_{\text{total}} = T_{\text{prearcing time}} + T_{\text{arcing time}}}$$

- **Type of fuse-**

(1) **Low Voltage** – Kit-Kat (Semi closed rewirable), HRC

(2) **High voltage** – Cartridge fuse, Liquid fuse, metal clad fuse.

■ Characteristics of fuse element-

➢ Low resistance ➢ Low melting point
➢ High conductive ➢ Free from oxidation

- **Alloy- Fuse** = Lead (37%) + Tin (63%)

  Fuse < 10A → Lead + Tin

  Fuse > 10A → Silver
- **HRC fuse** – High rupturing capacity fuse.
- **Difference between Isolator and Circuit breaker**

Isolator	Circuit Breaker
Manual operated	Manual and Automatic operated
Operated under no-load condition	Operated under load condition
It is used only as a switching device	Switching as well as protective device.

❑ Circuit Breaker

- ➢ A circuit breaker can make or break a circuit either manually or automatically under no-load, full load or short circuit condition.
- ➢ Circuit breaker is a protective device.

■ Classification of Circuit Breaker -

- ➢ Oil circuit breaker
- ➢ Air blast circuit breaker
- ➢ Gas circuit breaker or SF_6 circuit breaker
- ➢ Vacuum circuit breaker
- ➢ Air break circuit breaker

Oil circuit breaker
- Bulk oil circuit breaker
- Minimum oil circuit breaker

■ Properties of SF_6 Circuit Breaker -

- ➢ Good dielectric strength.
- ➢ Excellent arc quenching property.
- ➢ It is an electronegative.
- ➢ Pressure of SF_6 circuit breaker is generally should be 6 to 8 kg/cm^2.
- ➢ It is used 132 kV and above 132 kV.

Type	Arc quenching medium
Air break circuit breaker	Air at atmosphere
Vacuum circuit breaker	Vacuum
SF_6 circuit breaker	SF_6 gas at 5 kg/cm^2
Air blast circuit breaker	Air at 20-30 kg/cm^2

- **Rate of rise of restriking voltage-**

$$\boxed{(RRRV)_{\max} = \frac{V_m}{\sqrt{LC}}} \qquad \boxed{RRRV \propto \omega_0}$$

$$\boxed{(RRRV)_{\text{avg}} = \frac{2V_m}{\pi\sqrt{LC}}} \qquad \text{Unit} \rightarrow \text{kV}/\mu\text{ sec}$$

$$\boxed{\text{Making current } (I_m) = 2.55 \times \text{Breaking current } (I_B)}$$

❑ Relay

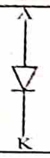
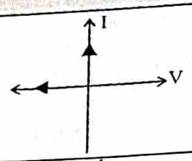
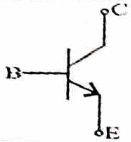
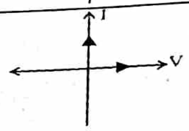
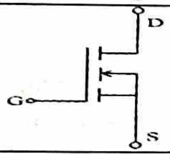
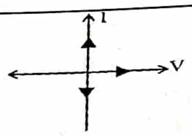
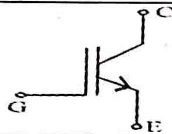
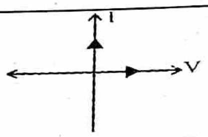
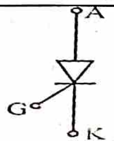
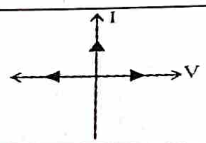
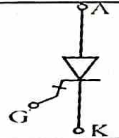
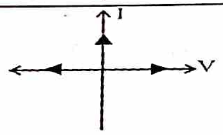
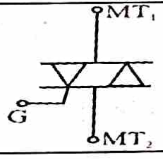
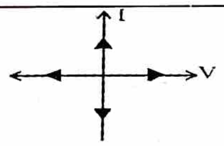
- ➢ Relays are sensing device. It consists of a set of input terminals for a single or multiple control signals, and a set of operating contact terminals.
- **Plug setting multiplier (P.S.M.)-**

$$\text{P.S.M} = \frac{\text{Fault current in relay coil}}{\text{Rated secondary current of CT} \times \text{Current setting}}$$

- ➢ PSM < 1.0 Relay will not operate.
- ➢ PSM = 1.0 Relay is on the wedge of operation.
- ➢ PSM > 1.0 Relay will definitely operate.
- **Distance relay-**
- ➢ Reactance Relay → Short transmission line
- ➢ Impedance Relay → Medium transmission line
- ➢ Mho Relay → Long transmission line
- ➢ For earth fault generally reactance relay are used.
- ➢ For complete protection of a 3-phase line, two-phase and one earth fault relays are required.

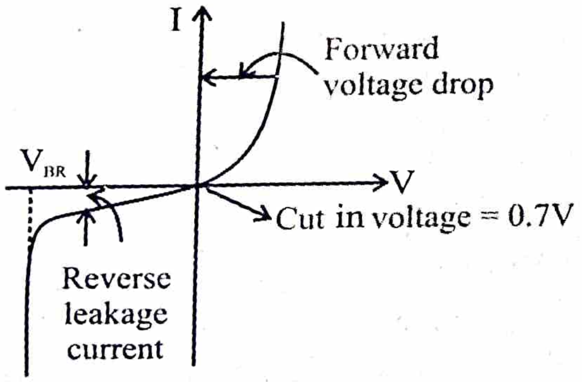
POWER ELECTRONICS & DRIVES

☐ Ideal Characteristics of Different Switches-

Switches	Symbol	Characteristic	Voltage/Current Rating
Diode			5000V 5000A
BJT (N-P-N)			1400 V 400 A
MOSFET (n-Channel)			1000 V 50 A
IGBT			1200 V 500 A
SCR			7000 V 5000 A
GTO			5000 V 3000 A
TRIAC			1200 V 1000A

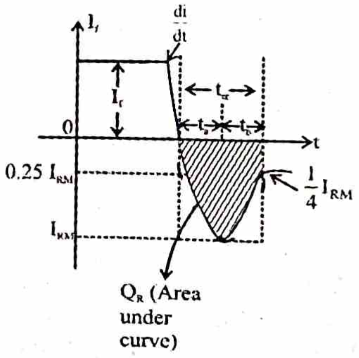
☐ Characteristic of Power Diodes

- **Diode V-I Characteristics (Forward characteristics)**



➢ Maximum applied reverse voltage = PIV

- **Reverse Recovery Characteristic**



➢ $\boxed{t_{rr} = t_a + t_b = t_{off}}$ $\boxed{t_{rr} = \left[\frac{2Q_R}{di/dt}\right]^{1/2}}$

$\boxed{I_{RM} = \left[2Q_R \frac{di}{dt}\right]^{1/2}}$

- Softness factor $(S) = \frac{t_b}{t_a}$
- when $S \to 1$, $t_a = t_b$ then soft recovery
  $S << 1$ fast recovery

- **Types of Power Diode :-**

Parameters	General Purpose Diode	Fast Recovery Diode	Schottky Diode
t_{rr}	25 μ sec	5μ sec or less	In nano sec
Voltage Rating	50V to 5kV	50V to 3 kV	Reverse voltage blocking capability limited to 100 Volts
Current rating	1 A to 1000 A	1 A - Several hundreds of Amp.	1 A to 300 A
Application	➢ Battery charging ➢ UPS ➢ Welding ➢ Electric traction	➢Choppers ➢Commutation circuits ➢ SMPS ➢ Induction heating	➢High frequency Instrumentation ➢Switching Power supplies

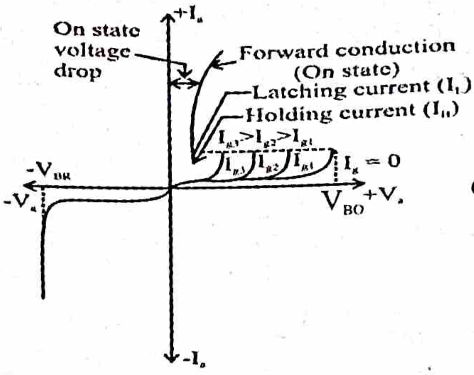
- **Power Transistors-**

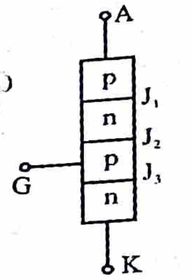
BJT	MOSFET	IGBT
Bipolar device	Unipolar device	Bipolar device
Low ON state voltage drop	High ON state voltage drop	Low ON state voltage drop
Low On state conduction power loss	High ON state conduction power loss	Low ON state conduction power loss
Negative temperature coefficient for resistance	Positive temperature coefficient for resistance	Positive temperature coefficient for resistance
High switching power loss	Low switching power loss	Low switching power loss
Low input Impedance	High Input Impedance	High Input Impedance
Current controlled device	Voltage controlled device	Voltage controlled device
1200 V, 800A (10-20)kHz	500V, 140A, 1MHz	1200V, 500A, 50kHz
Secondary Break down will occur	Secondary Break down will not occur	Secondary Break down will not occur.
Parallel operation is not advisable	Parallel operation is possible	Parallel operation is possible.
Application: UPS, charging batteries	SMPS	Inverters choppers.

☐ Thyristor

- ➢ Four layer ➢ 3 Junction ➢ 3 terminal
- ➢ Semi controlled device

- **Static V-I Characteristics of Thyristor-**





Schematic diagram

- **Latching current (I_L) :-** It is the minimum value of anode current during turn on process to maintain conduction when gate signal is removed.
- **Holding current (I_H) :-** It is the minimum value of anode current below which thyristor will return to forward blocking state or thyristor will turn off

$\boxed{I_{Latching} > I_{Holding}}$ or $I_{Latching} = (2 \text{ to } 2.5)\, I_{Holding}$

- **Operating Mode of Thyristor**

Operating mode	Junction1	Junction 2	Junction 3
Forward conduction	Forward	Breakdown	Forward
Forward Blocking	Forward	Reverse	Forward
Reverse Blocking	Reverse	Forward	Reverse

☞ Remember point

a. The Break down voltage reduces by increasing the magnitude of gate signal.

b. Latching current is used in turn on process & holding current is used in turn off process of SCR.

c. $I_L > I_H$

d. After SCR turn ON Gate loses its control that 's why it is called semi controlled device.

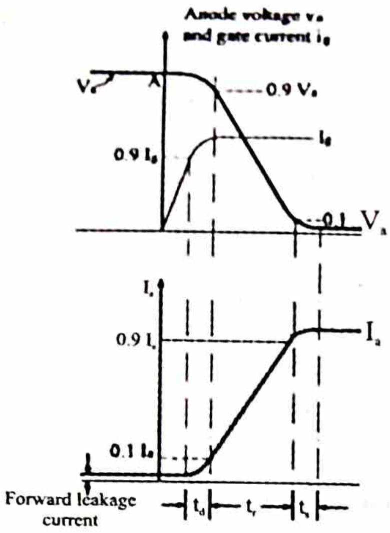
☐ Triggering Methods of SCR-

- ➢ Gate triggering
- ➢ Forward voltage triggering
- ➢ $\frac{dv}{dt}$ triggering
- ➢ Temperature triggering ➢ Light triggering

Note :- (i) Light triggering method used in HVDC transmission line.

(ii) Gate triggering is most preferable.

- **Switching Characteristic of SCR -**



Delay Time (t_d) :- The time at which gate current reaches 0.9 I_g to the instant at which anode current reach 0.1 I_a.

Rise Time (t_r) :- The time at which anode current to rise from 0.1 I_a to 0.9 I_a.

Spread Time (t_s) :- The time at which anode current to rise from 0.9 I_a to I_a.

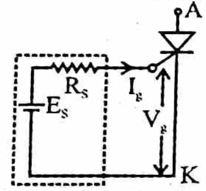
$\boxed{\text{Turn-on time} = t_d + t_r + t_s}$

⇒ If $t_c > t_q$ then Commutation is successful.

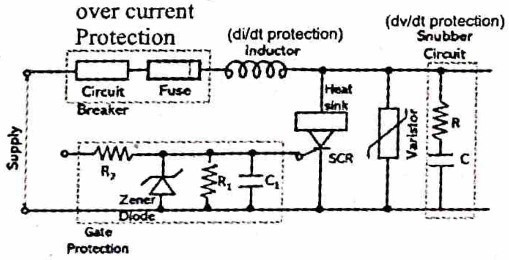
$t_c \rightarrow$ Circuit turn off time.

$t_q \rightarrow$ Device turn off time.

- **Gate Characteristics of SCR –**

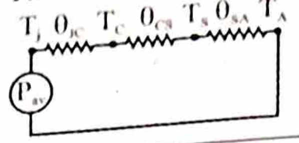
 A R_s E_s I_g V_g K Triggering Circuit	$\boxed{E_S = V_g + I_g R_S}$ $\boxed{P_g = V_g I_g}$

- **Protection of Thyristor -**


over current Protection
Circuit Breaker
Fuse
(di/dt protection) Inductor
Heat sink
(dv/dt protection) Snubber Circuit
Supply
R_2
Zener Diode
R_1
C_1
SCR
Varistor
R
C
Gate Protection

- ➢ Over current protection of SCR → Fuse + C.B.
- ➢ Over voltage protection of SCR → Varistor
- ➢ High dV/dt protection of SCR → Snubber circuit
- ➢ High di/dt protection of SCR → Inductor
- ➢ Thermal protection of SCR → Heat Sink
- ➢ Over current protection of gate → Resistance (R_2)
- ➢ Over voltage protection of gate → Zener diode
- ➢ Gate protection against noise → Capacitor (C_1) and resistance (R_1) across gate and cathode

- **Thermal Resistance :-**


T_J θ_{JC} T_C θ_{CS} T_S θ_{SA} T_A
P_{av}

$$\boxed{P_{av} = \frac{T_J - T_C}{\theta_{JC}} = \frac{T_C - T_S}{\theta_{CS}} = \frac{T_S - T_A}{\theta_{SA}} = \frac{T_J - T_A}{\theta_{JA}}}$$

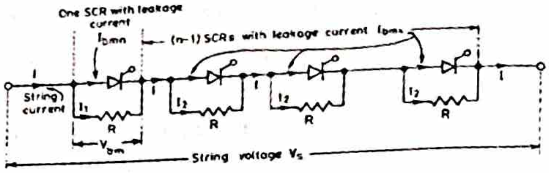
P_{av} - Average rate of heat generated by a thyristor

T_J - Junction temperature, θ - Thermal resistance

T_C-Case temperature, T_S - Sink temperature

T_A- Ambient temperature, $[\theta_{JA} = \theta_{JC} + \theta_{CS} + \theta_{SA}]$

- **Series Operation of SCR :-**


One SCR with leakage current I_{bmn}
(n-1) SCRs with leakage current I_{bmx}
I
String current
I_1
R
V_{bm}
I_2
String voltage V_s

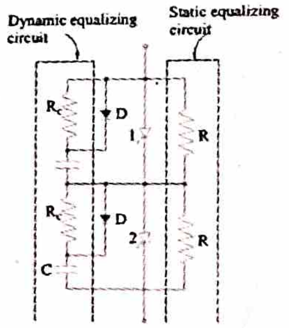
Static equalizing resistor $(R) = \dfrac{nV_{bm} - V_s}{(n-1)\Delta I_b}$

$$\{\Delta I_b = I_{b\max} - I_{b\min}\}$$

$$I = I_1 + I_{b\min}\ ,\quad I = I_2 + I_{b\max}$$

n = Number of series connected thyristor.

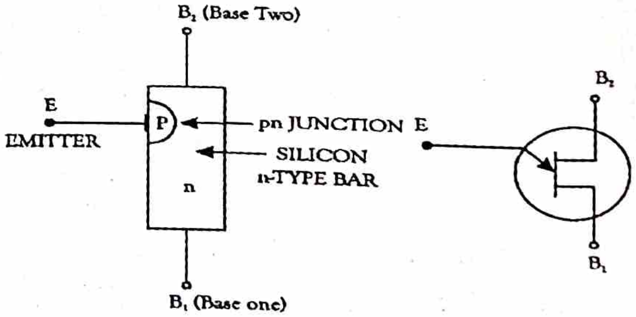
V_{bm} = Maximum blocking voltage.


Dynamic equalizing circuit
Static equalizing circuit
R_c
D
1
R
C
2

$$C = \frac{(n-1)\Delta Q_R}{nV_{bm} - V_S}$$

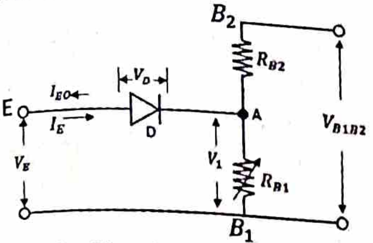
ΔQ_R = Difference in reverse recovery charge.

❑ UJT (Uni-Junction Transistor)


B_2 (Base Two)
E
EMITTER
P
n
pn JUNCTION
SILICON n-TYPE BAR
B_1 (Base one)
B_2
E
B_1

- ➢ A UJT is made of n-type lightly doped silicon base and p-type heavily doped embedded material.

Equivalent Circuit :-



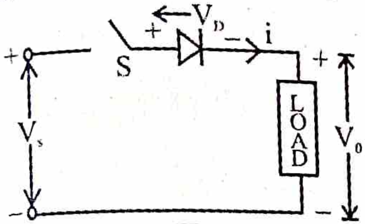
- Intrinsic stand-off ratio -

$$\boxed{\eta=\frac{R_{B_1}}{R_{B_1}+R_{B_2}}}\quad \eta=(0.51\text{ to }0.82)$$

- Peak point voltage $(V_P)=\eta\, V_{BB}+V_D$
  for turn-on UJT $V_E=V_P$
- UJT exhibits negative resistance characteristics, this makes the UJT to work as a Relaxation oscillator.

- **Application of UJT**
  - Phase control
  - Switching
  - Pulse generation
  - Sine wave generation
  - Saw tooth wave form generation
  - Timing circuit

☐ Diode Circuit With DC Source



Resistive Load	➢ $i(t)=\frac{V_s}{R}$
RC Load	➢ $i(t)=\frac{V_s}{R}e^{-t/RC}$ ➢ $V_C(t)=V_s\left(1-e^{-t/RC}\right)$ ➢ $\left(\frac{dV_C}{dt}\right)_{t=0}=\frac{V_s}{RC}$ ➢ $\tau=RC=\frac{\text{Source Voltage}(V_s)}{\left(\frac{dV_C}{dt}\right)_{t=0}}$
RL Load	➢ $i(t)=\frac{V_S}{R}\left(1-e^{-\frac{R}{L}t}\right)$ ➢ $V_L(t)=V_S.e^{-\frac{R}{L}t}$ ➢ $\left(\frac{di}{dt}\right)_{t=0}=\frac{V_S}{L}$
LC Load	➢ $i(t)=V_S\sqrt{\frac{C}{L}}\sin\omega_0 t$, $\omega_0=\frac{1}{\sqrt{LC}}$ ➢ $V_C(t)=V_S(1-\cos\omega_0 t)$ ➢ $V_L(t)=V_S\cos\omega_0 t$
RLC Load	➢Characteristic equation $s^2+\frac{R}{L}s+\frac{1}{LC}=0$ ➢Damping factor $\alpha=\frac{R}{2L}=\xi\omega_0$ ➢Ringing frequency $\omega_r=\sqrt{\omega_0^2-\alpha^2}$ in rad/ sec • **Case-1** $\alpha<\omega_0$ ➢ Roots are complex ➢ Under damped ➢ $i(t)=\frac{V_S}{\omega_r L}e^{-\alpha t}\sin\omega_r t$ • **Case -2** $\alpha>\omega_0$ ➢ Roots are real ➢ Over damped ➢ $i(t)=\frac{V_S}{L\sqrt{\alpha^2-\omega_0^2}}\sinh\left(\sqrt{\alpha^2-\omega_0^2 t}\right)$ • **Case-3** $\alpha=\omega_0$ ➢ Roots are equal ➢ Critically damped ➢ $i(t)=\frac{V_S}{L}.te^{-\alpha t}$

☐ Performance Parameter

If

V_S = RMS value of supply phase voltage

I_S = RMS value of supply phase current including fundamental and harmonics.

I_{S_1} = RMS value of fundamental component of supply current I_S

$P_{dc}=V_{avg}\,I_{avg}$ = DC output power

V_{avg} = Average output voltage.

I_{avg} = Average output current

Input power factor	$P.F=\frac{I_{S_1}}{I_S}\cos\phi$
RMS value of harmonic components	$I_h=\sqrt{I_s^2-I_{s_1}^2}$
Harmonic factor of Input current	$H.F=\frac{I_h}{I_{s_1}}$ or $H.F=\sqrt{\frac{I_s^2-I_{s_1}^2}{I_{s_1}^2}}$
Form factor	$FF=\frac{V_{or}}{V_{avg}}$

Displacement factor	$\cos\phi_1$
Ripple voltage (V_r)	$V_r = \sqrt{V_{or}^2 - V_{avg}^2}$
Voltage ripple factor (VRF)	$V_{RF} = \frac{V_r}{V_{avg}} = \sqrt{(FF)^2 - 1}$
Transformer Utilization factor (TUF)	$TUF = \frac{P_{dc}}{V_S I_S}$
Distortion factor (g)	$g = \frac{I_{s_1}}{I_s}$

Single Phase Half wave Controlled and Uncontrolled Rectifier

Fixed AC → Uncontrolled rectifier (diode) → Fixed DC

Fixed AC → Fully controlled rectifier (Thyristor) → Variable DC

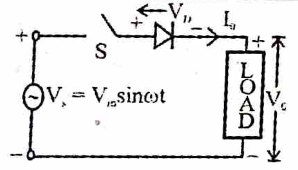
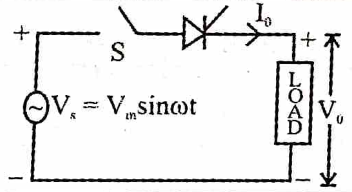
Fixed AC → Half controlled rectifier (Thyristor+diode) → Variable DC

(Two quadrant operation)

Pulse number (m) = The no. of output pulse for one cycle of AC source voltage.

Output of ripple frequency = mf = f_0

Pulse width/ period $= \frac{2\pi}{mf}$

Single phase half wave Diode Rectifier	**Single phase half wave controlled rectifier.**
 + S + V_D – I_0 + $V_s = V_m \sin\omega t$ LOAD V_0 – –	 + S I_0 + $V_s = V_m \sin\omega t$ LOAD V_0 – –
• **R-Load** ➢ $V_{rms} = \frac{V_m}{2}$ ➢ $V_0 = \frac{V_m}{\pi}$ ➢ $PIV = V_m$ ➢ $P = I_{rms}^2 R$ ➢ $P.F = \frac{V_{rms}.I_{rms}}{V_S.I_{rms}} = \frac{1}{\sqrt{2}}$	• **R-Load** ➢ $V_{rms} = \frac{V_m}{2\sqrt{\pi}}\left[(\pi-\alpha)+\frac{\sin 2\alpha}{2}\right]^{1/2}$ ➢ $V_0 = \frac{V_m}{2\pi}(1+\cos\alpha)$ ➢ $PIV = V_m$ ➢ $\gamma_T = \pi - \alpha$ ➢ $\beta = \pi$ ➢ $t_c = \pi/\omega$
• **R–L Load** ➢ $V_0 = \frac{V_m}{2\pi}(1-\cos\beta)$ ➢ $I_0 = \frac{V_m}{2\pi R}(1-\cos\beta)$ ➢ $\gamma_D = \beta \rightarrow$ Extinction angle of the diode.	• **R-L Load** ➢ $V_0 = \frac{V_m}{2\pi}(\cos\alpha - \cos\beta)$ ➢ $I_0 = \frac{V_m}{2\pi R}(\cos\alpha - \cos\beta)$ ➢ $\pi < \beta < 2\pi - \alpha$ ➢ $\gamma_T = \beta - \alpha$ ➢ $t_C = \frac{2\pi - \beta}{\omega}$
• **R-E Load** ➢ $I_0 = \frac{1}{2\pi R}[2V_m\cos\theta - E(\pi - 2\theta)]$ ➢ $V_0 = I_0 R + E$ ➢ $PIV = V_m + E$ ➢ $\gamma_D = \pi - 2\theta$	• **R-E Load** ➢ $I_0 = \frac{V_m \sin\omega t - E}{R}$ ➢ $\theta_1 = \sin^{-1}\left[\frac{E}{V_m}\right]$ ➢ $V_0 = \frac{1}{2\pi}[V_m(\cos\alpha - \cos\theta_2) + E(2\pi + \alpha - \theta_2)]$ ➢ $\gamma_T = \pi - \theta_1 - \alpha$ ➢ $t_C = \frac{\pi + 2\theta_1}{\omega}$

➢ **Advantage of freewheeling diode –**

1. Improves power factor
2. Load current waveform is improved
3. Negative spikes in output voltage are removed.
4. Load performance is better
5. As energy stored in L is transferred to R during the freewheeling period. Hence overall converter efficiency improves.

Single Phase Full Wave Controlled Rectifier

RL Load

Continuous	**Discontinuous**
$V_0 = \frac{2V_m\cos\alpha}{\pi}$ $V_{rms} = \frac{V_m}{\sqrt{2}}$ $t_c = \frac{\pi - \alpha}{\omega}$	$V_0 = \frac{V_m}{\pi}(\cos\alpha - \cos\beta)$ $V_{rms} = \frac{V_m}{\sqrt{2\pi}}\left[(\beta-\alpha)+\frac{1}{2}(\sin 2\alpha - \sin 2\beta)\right]^{\frac{1}{2}}$ $t_c = \frac{2\pi - \beta}{\omega}$

RLE Load

Continuous	**Discontinuous**
$V_0 = \frac{2V_m\cos\alpha}{\pi}$ $V_{rms} = V_s$ $t_c = \frac{\pi - \alpha}{\omega}$	$V_0 = \frac{1}{\pi}[V_m(\cos\alpha - \cos\beta) + E(\pi + \alpha - \beta)]$ $t_c = \frac{2\pi + \theta_1 - \beta}{\omega}$ $I_0 = \frac{V_0 - E}{R}$

R Load

$$V_0 = \frac{V_m}{\pi}(1+\cos\alpha)$$

$$V_{rms} = \frac{V_m}{\sqrt{2\pi}}\left[(\pi-\alpha)+\frac{1}{2}\sin 2\alpha\right]^{\frac{1}{2}}$$

$$t_c = \frac{\pi}{\omega}$$

☐ Comparison of Semi Controlled Full Wave Bridge Rectifier

Parameters	Symmetrical	Asymmetrical	FWD + full wave converter
V_0	$\frac{V_m}{\pi}(1+\cos\alpha)$	$\frac{V_m}{\pi}(1+\cos\alpha)$	$\frac{V_m}{\pi}(1+\cos\alpha)$
I_{srms}	$I_0\sqrt{\frac{\pi-\alpha}{\pi}}$	$I_0\sqrt{\frac{\pi-\alpha}{\pi}}$	$I_0\sqrt{\frac{\pi-\alpha}{\pi}}$
I_{Tavg}	$I_0/2$	$I_0\left[\frac{\pi-\alpha}{2\pi}\right]$	$I_0\left[\frac{\pi-\alpha}{2\pi}\right]$
I_{Davg}	$\frac{I_0}{2}$	$I_0\left[\frac{\pi+\alpha}{2\pi}\right]$	$I_0\frac{\alpha}{\pi}$

☐ Three Phase Half Wave Controlled and Uncontrolled Rectifier

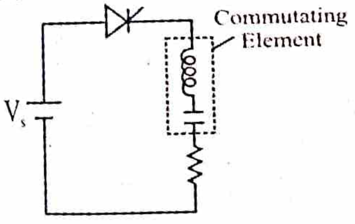
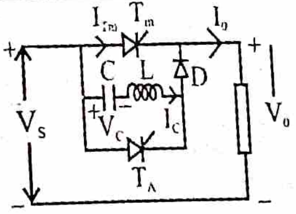
3ϕ half wave uncontrolled rectifier	3-ϕ half wave controlled rectifier (3 pulse)
➢ $V_{0avg}=\frac{3\sqrt{3}V_m}{2\pi}$	• $\alpha \le 30°$ (continuous conduction) ➢$V_{avg}=\frac{3\sqrt{3}}{2\pi}V_m\cos\alpha$ for • $\alpha > 30°$ only for R load (discontinuous conduction) ➢$V_{avg}=\frac{3V_m}{2\pi}(1+\cos(\frac{\pi}{6}+\alpha))$

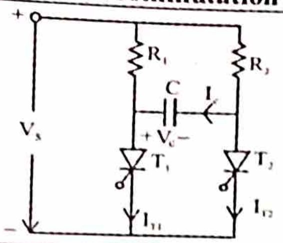
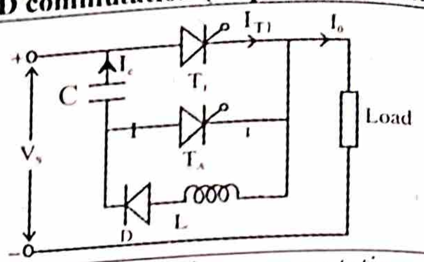
☐ 3–ϕ Full Wave Controlled Bridge Rectifier (6 pulse)-

3–ϕ full controlled Bridge Rectifier	3–ϕ half controlled bridge rectifier or 3-ϕ semiconverter
•For $\alpha \le 60°$ R and R-L-Load & RLE load for any α value ➢ $V_{avg}=\frac{3V_{ml}}{\pi}\cos\alpha$ ➢ $t_C \simeq \frac{\frac{4\pi}{3}-\alpha}{\omega}$ • **For α > 60° (valid for only R load)** ➢ $V_{avg}=\frac{3V_{ml}}{\pi}[1+\cos(\alpha+\frac{\pi}{3})]$ ➢ $t_C=\frac{\pi-\alpha}{\omega}$	• For $\alpha \le 60°$ ➢ $V_{avg}=\frac{3V_{ml}}{2\pi}(1+\cos\alpha)$ • For $\alpha \ge 60°$ ➢ $V_{avg}=\frac{3V_{ml}}{2\pi}(1+\cos\alpha)$ **Note-** In 3-ϕ semi controlled rectifier ➢ $\alpha < 60° \rightarrow 6\text{pulse}$ ➢ $\alpha \ge 60° \rightarrow 3\text{pulse}$

■ Commutation technique

- **Natural/Line commutation-** If nature of supply supports commutation process then it is called natural commutation. Eg. Rectifiers, AC voltage controller, step-down cyclo converter.
- **Forced commutation-** DC supply not support the commutation process. Eg. Chopper, inverter, step-up cycloconverter.

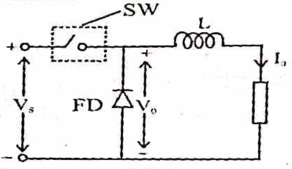
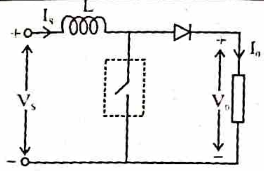
Class A (Load Commutation)	Class B-Commutation (Current commutation)
	 I_{Tm} T_m I_0 + C L D V_S V_C I_C T_A V_0 –
Over all circuit must be under damped $R^2 < \frac{4L}{C}$	Resonant current $I_C = -V_S\sqrt{\frac{C}{L}}\sin\omega_0 t = -I_P\sin\omega_0 t$
Class A commutation possible in DC circuit only not in AC.	Peak resonant current $I_P = V_S\sqrt{\frac{C}{L}}$
It is also known as resonant commutation or self commutation	Circuit turn off time $t_C=\frac{C\,V_{ab}}{I_0}$ Reverse voltage across main thyristor $V_{ab}=V_S\cos\left[\sin^{-1}\left[\frac{I_0}{I_P}\right]\right]$ Auxiliary thyristor conduction time = $\pi\sqrt{LC}$

Class C commutation (Complementary commutation)	Class D commutation (Impulse commutation)
 + V_s R₁ R₂ C I +V_c− T₁ T₂ I_{T1} I_{T2} −	 + C I_c I_{T1} I₀ T₁ Load V_s I T_A L D −
Case 1- $T_1 \rightarrow$ ON & $T_2 \rightarrow$ OFF at $t = 0$ $I_{T1} = \frac{V_s}{R_1} + \frac{2V_S}{R_2} e^{-t/R_2C}$, $V_{C1} = V_S[1 - e^{-t/R_1C}]$	Also known as Impulse commutation, voltage commutation. Capacitor current $I_C = V_S\sqrt{\frac{C}{L}} \sin \omega_0 t$
Case 2 - $T_1 \rightarrow$ OFF & $T_2 \rightarrow$ ON at $t = t_1$ $I_{T2} = \frac{V_s}{R_2} + \frac{2V_S}{R_1} e^{-t/R_1C}$, $V_{C2} = V_S[2e^{-t/R_2C} - 1]$	Peak value of current $I_P = V_S\sqrt{\frac{C}{L}}$
Peak current through T_1, $I_{T_1} = V_S\left[\frac{1}{R_1} + \frac{2}{R_2}\right]$	Circuit turn off time for main thyristor, $t_c = C\frac{V_s}{I_0}$
Peak current through T_2, $I_{T_2} = V_S\left[\frac{2}{R_1} + \frac{1}{R_2}\right]$	Circuit turn off time for auxiliary thyristors (T_A), $t_c = \frac{\pi}{2}\sqrt{LC}$
Circuit turn off time for T_1 & T_2 $t_{C1} = R_1C\ \ell n(2)$, $t_{C2} = R_2C\ \ell n(2)$	Peak value of current through auxiliary thyristor (T_A) = I_0 and main thyristor (T_M) = $I_0 + V_s\sqrt{\frac{C}{L}}$

■ DC Drives-

Separately-Excited DC motor	DC Series motor
Voltage across field winding $V_f = I_f \cdot r_f$	Motor terminal voltage $V_t = E_a + I_a(r_a + r_s)$
Motor terminal voltage $V_t = E_a + I_a r_a$	Motor torque $T_e = k_a\phi I_a$ For no saturation in the magnetic circuit
Motor back Emf $E_a =$ $k_a\phi\omega_m = k_m\omega_m$	Motor torque $T_e = kI_a^2$
Motor torque $T_e = k_m I_a$	Motor back Emf $E_a = kI_a\omega_m$
Angular speed of motor $\omega_m = \frac{V_t - I_a r_a}{k_m}$	Angular speed of motor $\omega_m = \frac{V_t}{KI_a} - \frac{(r_a + r_s)}{K}$

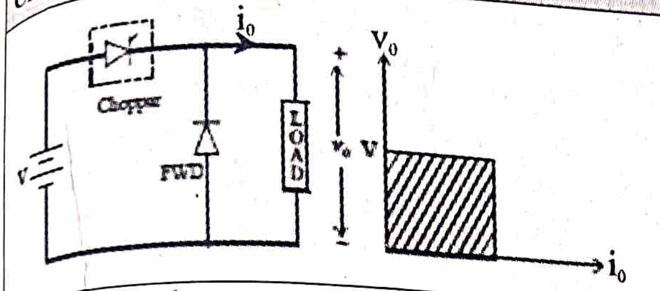
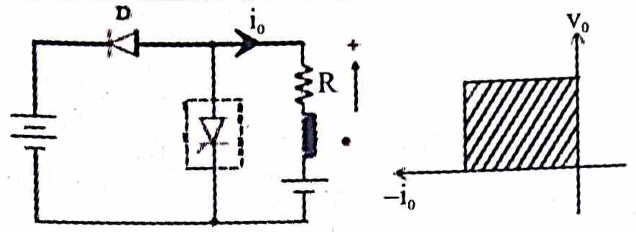
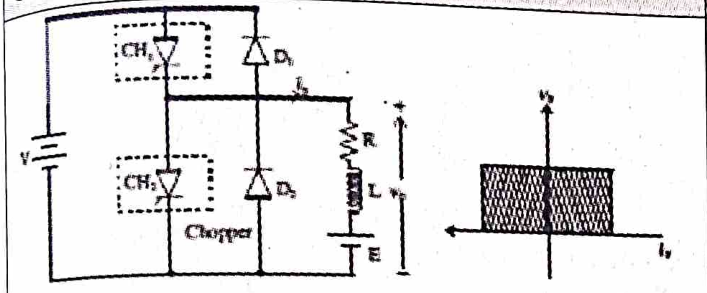
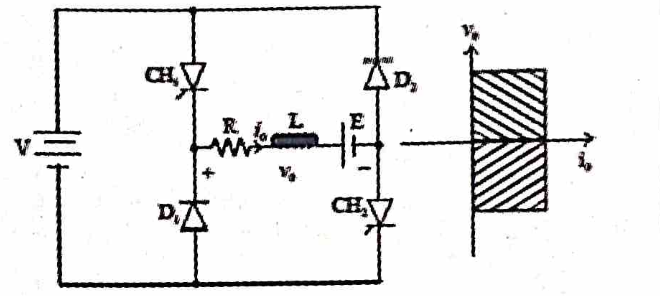
■ Choppers

Step Down Chopper (Buck converter)	Step up chopper (Boost converter)
 SW L + V_s FD V₀ I₀ − ➤ Average Voltage $V_0 = \alpha V_S$ ➤ (duty cycle) α $= \frac{T_{ON}}{T} = \frac{T_{ON}}{T_{ON} + T_{OFF}}$ $V_0 = fT_{ON}V_S$ $\left(f = \frac{1}{T}\right)$ ➤ $V_{rms} = \sqrt{\alpha}\ V_S$ ➤ $I_{rms} = \frac{\sqrt{\alpha}}{R} V_S$ f = Chopping frequency T = Chopping period	 $V_0 = \frac{1}{1-\alpha} V_S$ $V_{rms} = \frac{1}{\sqrt{1-\alpha}} V_S$

- **Type-A Chopper Steady State Time Domain Analysis.**

Load current continuous	Load current Discontinuous
$I_{max} = \frac{V_S}{R}\left[\frac{1 - e^{-T_{on}/T_a}}{1 - e^{-T/T_a}}\right] - \frac{E}{R}$ $I_{min} = \frac{V_s}{R}\left[\frac{e^{T_{ON}/T_a} - 1}{e^{T/T_a} - 1}\right] - \frac{E}{R}$	$I_{max} = \frac{V_S - E}{R}\left(1 - e^{-T_{ON}/T_a}\right)$ $I_{min} = 0$

- *Classification of Chopper*

Class A	**Class-B**
 i0 V0 Chopper FWD LOAD V + v0 V i0	
First quadrant chopper	Second quadrant chopper
Step-down chopper, in which power always flow from source to load.	Power flow from load to source
Used to control the speed of DC motor	Used for regenerative braking of DC motor
Class C	**Class D**
 CH1 D1 i0 V R L v0 CH2 D2 Chopper E v0 i0	 CH1 D2 V R i0 L E + v0 – D1 CH2 v0 i0

☐ Single Phase Half Bridge Inverter

Single Phase half Bridge Inverter with R Load	**Single Phase half bridge inverter with L load**	**Single phase half bridge Inverter for RL load**	**Single phase half bridge Inverter with RLC load**
$V_{0\,rms} = \frac{V_{dc}}{2}$	$V_{0\,rms} = \frac{V_{dc}}{2}$	$V_{rms} = \frac{V_{dc}}{2}$	$V_0 = \frac{V_{dc}}{2}$
$V_0(t) = \sum_{n=1,3,5}^{\infty} \frac{2V_{dc}}{n\pi} \sin n\omega_0 t$ $P_{01} = V_{01rms}\ I_{01rms}$	$\gamma_{each\ diode} = \gamma_{each\ thyristor} = \frac{\pi}{2}$	$\gamma_{each\ diode} = \phi$; $\gamma_{each\ thyristor} = \pi - \phi$	$\gamma_{each\ diode} = \phi$; $\gamma_{each\ thyristor} = \pi - \phi$
$V_{01}(t) = \frac{2V_{dc}}{\pi} \sin \omega_0 t$	$\gamma_D = \gamma_T = \pi$	$I_0(t) = \sum_{n=1,3,5}^{\infty} \frac{2V_{dc}}{\lvert Z_n \rvert n\pi} \times$ $\sin(n\omega_0 t - \phi_n)$	$t_c = \frac{\phi}{\omega}$
THD = 48.43%	$I_{T01(rms)} = \frac{I_{01max}}{2\sqrt{2}}$ $Q_{01} = V_{01rms}\ I_{01rms}$.	$\phi_n = \tan^{-1}\left(\frac{n\omega_0 L}{R}\right)$ $\lvert Z_n \rvert = \sqrt{R^2 + n^2\omega_0^2 L^2}$	$I_0(t) = \sum_{n=1,3,5}^{\infty} \frac{2V_{dc}}{\lvert Z_n \rvert n\pi} \sin(n\omega_0 t \pm \phi_n)$
$I_{01} = \frac{2V_{dc}}{R\pi} \sin \omega_0 t$ $V_{01rms} = \frac{\sqrt{2}V_{dC}}{\pi}$	$I_0(t) = \sum_{n=1,3,5}^{\infty} \frac{2V_{dc}}{n^2\omega_0 L\pi}$ $\sin n(\omega_0 t - \pi/2)$ FDF = cos90° = 0	F.D.F = cos ϕ_1 $P_{01} = V_{01rms}\ I_{01rms} \cos \phi_1$ $Q_{01} = V_{01rms} I_{01rms} \sin \phi_1$	$\lvert Z_n \rvert = \sqrt{R^2 + (n\omega_0 L - \frac{1}{n\omega_0 C})^2}$ $\phi_n = \tan^{-1}\left[\frac{n\omega_0 L - \frac{1}{n\omega_0 C}}{R}\right]$

❑ Single Phase Full Bridge Inverter

Single phase full bridge Inverter for R	**Single phase full bridge Inverter for L**	**Single phase full bridge Inverter for RL**	**Single phase full bridge Inverter for RLC**
$V_{rms} = V_{dc}$	$V_{0rms} = V_{dc}$	$V_{0rms} = V_{dc}$	$V_{0rms} = V_{dc}$
$\gamma_{\text{each thyristor}} = \pi\,;\ \gamma_{\text{each diode}} = 0$	$\gamma_{diode} = \gamma_{thyristor} = 180°$	$\gamma_{\text{each diode}} = \phi\,;$ $\gamma_{\text{each thyristor}} = \pi - \phi$	$\gamma_{\text{each diode}} = \phi$ $\gamma_{\text{each thyristor}} = \pi - \phi$
$V_0(t) = \sum_{n=1,3,5}^{\infty} \frac{4V_{dc}}{n\pi} \sin n\omega_0 t$	$I_{Tavg} = \frac{I_{0\max}}{8}\,;\ I_{Trms} = \frac{I_{0\max}}{\sqrt{2}}$	$I_0(t) = \sum_{n=1,3,5}^{\infty} \frac{4V_{dc}}{\lvert Z_n \rvert n\pi} \times$ $\sin(n\omega_0 t - \phi_n)$	$I_0(t) = \sum_{n=1,3,5}^{\infty} \frac{4V_{dc}}{\lvert Z_n \rvert n\pi} \times$ $\sin(n\omega_0 t \pm \phi_n)$
$I_0(t) = \sum_{n=1,3,5}^{\infty} \frac{4V_{dc}}{n\pi R} \sin n\omega_0 t$	$I_0(t) = \sum_{n=1,3,5}^{\infty} \frac{4V_{dc}}{n^2\omega_0 L\pi} \times$ $\sin n(\omega_0 t - \pi/2)$	$\phi_n = \tan^{-1}\left(\frac{n\omega_0 L}{R}\right)$ $\lvert Z_n \rvert = \sqrt{R^2 + (n\omega_0 L)^2}$	$P_{01} = V_{01rms} I_{01rms} \cos\phi_1$ $Q_{01} = V_{01rms} I_{01rms} \sin\phi_1$
$P_{01} = I_{01rms}^2 . R$ $P_{S01} = \frac{V_{dC}}{2} \times I_{S01(avg)}$ $\left\{\because I_{S01(avg)} = \frac{I_{01\max}}{\pi}\right.$	$P_{01} = V_{01rms} I_{01rms} \cos\phi_1 = 0$ $Q_{01} = V_{01rms} I_{01rms} \sin\phi_1 = V_{01rms} I_{01\,rms}$	$P_{01} = V_{01rms} \times I_{01rms} \cos_{\phi 1}$ $Q_{01} = V_{01rms} I_{01rms} \sin\phi_1$	$\phi_n = \tan^{-1}\left[\frac{n\omega_0 L - \frac{1}{n\omega_0 C}}{R}\right]$ $\lvert Zn \rvert = \sqrt{R^2 + \left[n\omega_0 L - \frac{1}{n\omega_0 C}\right]^2}$

☞ **Remember point for RLC Load-**

i. Case-1 - $X_L > X_C$ → Overdamped → the thyristor is not self commutated. It is force commutated (Lag P.F)

ii. Case -2 - $X_C > X_L$ → Underdamped → the thyristor is self commutated (Lead p.f)

iii. Circuit turn off time- $t_C = \frac{\phi}{\omega_0}$ $\left\{\because \phi = \tan^{-1}\left[\frac{X_C - X_L}{R}\right]\right.$

❑ 3 Phase Bridge Inverter

180^0 Phase	**120^0 Phase**
$(V_P)_{rms} = \frac{\sqrt{2}}{3} V_{dC}$	$(V_P)_{rms} = \frac{V_{dC}}{\sqrt{6}}$
$V_P(t) = \sum_{n=6k\pm1} \frac{2V_{dC}}{n\pi} \sin n\omega_0 t$	$V_P(t) = \sum_{n=1,3,5...}^{\infty} \frac{2V_{dC}}{n\pi} \sin\frac{n\pi}{3}$ $\sin(n\omega_0 t + \frac{n\pi}{6})$
$V_{01rms} = \frac{\sqrt{2}V_{dC}}{\pi}$	$(V_{01})_{rms} = \frac{\sqrt{2}V_{dC}}{\pi} \sin\frac{\pi}{3}$
$g = \frac{(V_{01})_{rms}}{(V_P)_{rms}} = \frac{3}{\pi}$	$g = \frac{(V_{01})_{rms}}{(V_P)_{rms}} = \frac{3}{\pi}$
T.H.D.= $\sqrt{\frac{1}{g^2} - 1} = 31\%$	T.H.D. = 31%
$P_Y = \frac{3V_P^2}{R} = 3I_P^2 R$	$P_Y = \frac{3V_P{}^2}{R} = 3I_P{}^2 R$

❑ Pulse Width Modulated Inverters

We can control the output voltage along with a frequency within the inverter itself without increasing the number of stages.

- **Single-pulse modulation-**

➢ Output Voltage

$$V_0(t) = \sum_{n=1,3,5}^{\infty} \frac{4V_{dc}}{n\pi} \sin\frac{n\pi}{2} \sin nd \sin n\omega t$$

➢ Pulse width = 2d

➢ RMS value of output voltage

$$\boxed{V_{rms} = V_{dc}\left[\frac{2d}{\pi}\right]^{1/2}}$$

➢ THD = $\sqrt{\frac{1}{g^2} - 1}$

☞ Remember Point

For n^{th} harmonic elimination pulse width $2d = \frac{2\pi}{n}$

- **Multiple Pulse Width Modulation-**

➢ Output voltage

$$V_0 = \sum_{n=1,3,5}^{\infty} \frac{8V_{dc}}{n\pi} \sin n\gamma \sin\frac{nd}{2} \sin n\omega t$$

$$\gamma = \frac{\pi - 2d}{N+1} + \frac{d}{N}$$

Where, N = Number of pulse/half cycle

➢ Condition to eliminate n^{th} harmonic

(i) $\gamma = \frac{\pi}{n}$ (ii) $2d = \frac{4\pi}{n}$

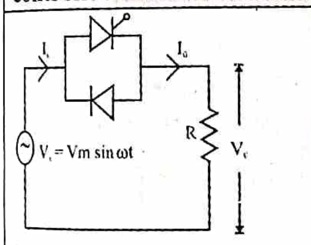
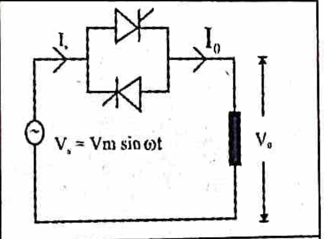
Note : In PWM inverter force commutation is essential

Current Source Inverter

- Feedback diode is not required in CSI.
- For capacitive load there is possibility of load commutation.
- Inherently there is a short circuit protection for the source when the incoming thyristor are switched on before the outgoing thyristor becomes off.

For R Load	For C load
$I_{0rms} = I_s$ $V_{0rms} = I_{0rms} \times R$	$I_{T(avg)} = \frac{I_s}{2}$; $I_{T(rms)} = \frac{I_s}{\sqrt{2}}$
$I_{Tavg} = \frac{I_s}{2}$ $I_{Trms} = \frac{I_s}{\sqrt{2}}$	$I_0(t) = \sum_{n=1,3,5}^{\infty} \frac{4I_s}{n\pi} \sin n\omega_0 t$
$I_0(t) = \sum_{n=1,3,5}^{\infty} \frac{4I_s}{n\pi} \sin n\omega t$ $V_0(t) = \sum_{n=1,3,5}^{\infty} \frac{4I_s R}{n\pi} \times \sin n\omega_0 t$	$V_0(t) = \sum_{n=1,3,5}^{\infty} \frac{4I_s}{n\pi} \times$ $\left(\frac{1}{n\omega_0 C}\right) \sin n\omega_0 t - \frac{n\pi}{2}$
$g = \frac{2\sqrt{2}}{\pi}$ THD = 48.43%	$V_{0\max} = \frac{I_s T}{4C}$
$P_{01} = I_{01rms}^2 R$, $\gamma_T = \pi$	$I_{T01ms} = \frac{I_{01\max}}{2}$, $\gamma_T = \pi$

Voltage Controllers

Half wave AC voltage controller	Full wave AC voltage controller
	
Rms value of output voltage $V_{rms} = \frac{V_m}{2}[\frac{1}{\pi}\{(2\pi - \alpha) + \frac{\sin 2\alpha}{2}\}]^{1/2}$	Rms value of output voltage for R-Load $V_{rms} = \frac{V_m}{\sqrt{2}}[\frac{1}{\pi}\{(\pi - \alpha) + \frac{1}{2}\sin 2\alpha\}]^{1/2}$
Average value of output voltage $V_0 = \frac{V_m}{2\pi}(\cos\alpha - 1)$	Rms value of output voltage for RL - Load $V_{rms} = \frac{V_m}{\sqrt{2}\pi}[(\beta - \alpha) + \frac{1}{2}(\sin 2\alpha - \sin 2\beta)]^{1/2}$

☞ Remember point

For Full Wave AC Voltage Controller-

- For RL Load output voltage is controllable only When $\alpha > \phi$ where $\phi = \tan^{-1}\frac{\omega L}{R}$
- Range of α for getting controllable output voltage $\boxed{\phi \le \alpha \le 180°}$
- Average value of output voltage would be zero.

Integral Cycle Control-

This is used for load which have high time constant.

- **Rms value of output voltage**

$$V_{rms} = V_s\sqrt{k} \left\{\because k = \frac{n}{n+m}\right.$$

Where, n = Number of ON cycle
m = Number of OFF cycle

- Power delivered to Load $P = \frac{kV_s^2}{R}$
- Input power factor $P.F = \sqrt{\frac{n}{n+m}} = \sqrt{k}$

Cycloconverter

Properties	• It converts AC signal of fixed frequency to AC signal with variable frequency. • It is also referred as frequency changer. • It is AC to AC converter without using any DC link. • It is a one stage frequency converter.
Classification	⇒ Based on output frequency • Step up cycloconverter [$f_0 > f_i$] • Step down cycloconverter [$f_0 < f_i$] ⇒ Based on phase input and phase output • 1 phase to 1 phase cycloconverter • 3 phase to 3 phase cycloconverter
Applications	• Induction heating. • Static VAr generation. • HVDC transmission line. • Speed control of AC drives. • Variable frequency supply for aircraft.

➢ Miscellaneous :-

- An inter-group reactor is used in a 1-ϕ cyclo-converter circuit to limit circulating current.
- Cycloconverter drives are generally employed in generating low frequency.
- To get minimum harmonic distortion in output, a 3-ϕ to 3-ϕ cycloconverter requires 36 SCRs.
- In a 1-ϕ to 1-ϕ cycloconverter, the magnitude of harmonic components are large and this can be reduced by using a 3-ϕ input supply.
- 1-ϕ mid-point type cycloconverter uses 4 SCRs (2 negative and 2 positive)
- 1-ϕ bridge type cycloconverter uses 8 SCRs (4 negative and 4 positive)
- In a 3-ϕ half-wave cycloconverter both inverting and converting action takes place.
- All type of cycloconverters are phase commutated except step up cycloconverter. The step up cycloconverter is forced commutated.

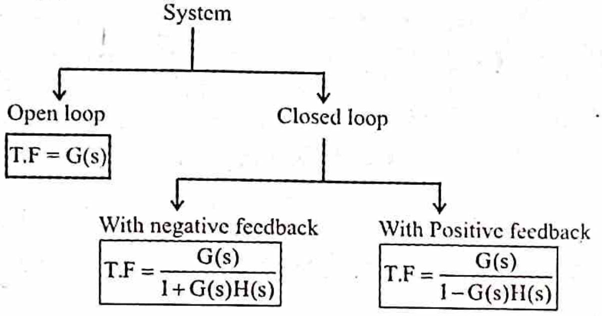
CONTROL SYSTEM

☐ Control system

Control system : A control system is a device that will manage, command, direct or regulate the behaviour of other devices using control loops.

A control system working under unknown random action is called stochastic control system.

■ Types of system



- ➢ For closed loop system open loop transfer function is G(s) H(s).
- ➢ For H(s) = 1, $G(s) = \frac{CLTF}{1-CLTF} = OLTF$

$$CLTF = \frac{OLTF}{1+OLTF}$$

- **System DC gain :**
- ➢ System DC gain in time constant form of transfer function corresponds to final value (or) steady-state value of unit step response.
- ➢ DC gain of CLTF $T(s)|_{S=0}$
- ➢ DC gain of OLTF = $G(s)|_{S=0}$
- **Examples of closed loop and open loop system-**

Closed loop	Open loop
Electric iron	Traffic light controller.
Water level controller	Electric washing machine.
A missile launching system	Automatic coffee server.
Radar tracking system	Bread Toaster.
Human respiratory system	TV remote
An air conditioner	Immersion rod

- **Comparison between open loop & closed loop system -**

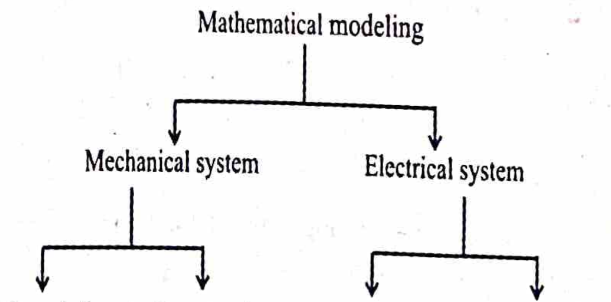
Open loop	Closed loop
More stable (no factor to affect stability)	Less stable (stability depends on the loop gain G(s) H(s))
Accuracy depends on input & process.	Accuracy depends on feedback network ratio. If feedback network use the stable value, then the closed loop system becomes highly accurate.
More sensitive for disturbance, noise and environmental condition	Less sensitive for disturbance, noise and environment (change in output very less).
Low Bandwidth (Bandwidth represent the speed of response). $\boxed{BW = \frac{0.35}{t_r}}$ Where, t_r= rise time	With feedback gain reduced by factor 1+G(s) H(s). ∴ Bandwidth is increased by a factor of 1+G(s)H(s)
More reliable (less number of components)	Less reliable.

- ➢ Negative feedback is best because it improves relative stability.
- ➢ Steady state error valid only for unity feedback system.
- **Advantages and Disadvantages of closed loop over open loop system**

Advantage	Disadvantages
Accurate and reliable	System is complex and costly.
Bandwidth of the system increases with negative feedback	Gain of the system reduces with negative feedback
Reduced Effect on parameter variation. (ex-RLC network)	Stability depends on system components. So, System may become unstable.
Reduced effect of non-linearities	Feedback leads to an oscillatory response
Better performance	

☐ Modeling of control system

■ Mathematical model of control system.



- **Force voltage and force current analogy**

Mechanical		**Electrical**	
Translational	**Rotational**	**Force-voltage analogy**	**Force-current analogy**
Force (F)	Torque (T)	Voltage (V)	Current (I)
Mass (M)	Inertia (J)	Inductance (L)	Capacitance (C)
Friction constant (B)	Torsional Friction Constant (B)	Resistance (R)	1/R
Spring Constant (K)	Torsional spring Constant (K)	Reciprocal of Capacitance (1/C)	1/L
Displacement (x)	Angular displacement (θ)	Charge (Q)	Flux (ϕ)
Velocity $\dot{x}=\frac{dx}{dt}=v$	Angular velocity $\dot{x}=\frac{d\theta}{dt}=\omega$	Current $i=\frac{dQ}{dt}$	Voltage $e=\frac{d\phi}{dt}$

➤ Transfer function (Valid only for linear time invariant) $T.F=\left.\frac{L[\text{output}]}{L[\text{input}]}\right|_{\text{initial conditon}=0}$

➤ A system with zero initial condition is said to be at rest since there is no stored energy.

➤ Characteristic equation is the denominator equated to zero for closed loop C.S. → $1+G(s)\,H(s)=0$
The roots of characteristic equation is called poles.

➤ Pole affect the system stability, system response and time constant, but zero not affect anyone.

➤ Time constant gives the system behaviour. If time constant is very large then it is called slow response system.
Practically any system takes the five time constant to reach steady state.

- **Servomechanism**

Servo Application	**Transfer function**
Armature controlled DC servomotor	$\frac{\theta(s)}{E_a(s)}=\frac{K_m}{s(s\tau_m+1)},\ \frac{\omega(s)}{E_a(s)}=\frac{K_m}{(s\tau_m+1)}$ K_m = motor gain constant τ_m = motor time constant
Field controlled DC servomotor	$\frac{\theta(s)}{E_f(s)}=\frac{K_m}{s(s\tau_f+1)(s\tau_{mech}+1)}$ τ_f = Field winding time constant τ_{mech} = Mechanical time constant
AC servomotor	$\frac{\omega(s)}{V_C(s)}=\frac{K_m}{(\tau_m s+1)}$
Potentiometer	$\frac{E_0(s)}{X_i(s)}=K_P$ K_P = Potentiometer gain constant.
Tachometer	$\frac{E(s)}{\omega(s)}=K_{tg}$ $\boxed{e\propto\omega}$ K_{tg} = Tacho-generator constant.

➤ The use of tacho-generator can be measured by the use of speed.

➤ Potentiometer is not a final control element.

➤ Synchro-Resolver devices is used for conversion of co-ordinates.

➤ Saturation is the non-linearity caused by servomotor.

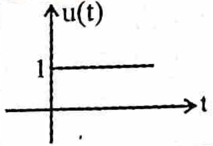
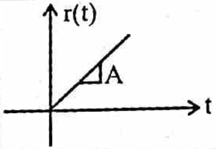
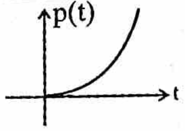
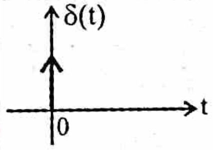
➤ Electric actuators for stepped motion are known as stepper motor.

- **Advantages of AC servomotor over DC servomotor**

1. Having small area of brush contact so losses are less.
2. Used for low power applications.
3. More efficient, reliable, reduces radio frequency and noise.
4. In absence of a commutator, requires less maintenance and have longer life.

❑ Transfer Function, Block Diagram and Signal flow Graph-

■ Signals

Types of signal	**Graph**	**Representation**
Unit step signal		$u(t)=\begin{cases}1;t>0\\0;t<0\end{cases}$
Ramp signal		$r(t)=\begin{cases}At\ ;t>0\\0\ ;t<0\end{cases}$ $r(t)=t\,u(t)$
Parabolic signal		$p(t)=\begin{cases}\frac{At^2}{2}\ ;t>0\\0\ ;t<0\end{cases}$
Impulse signal "Weighting function"		$\delta(t)=\begin{cases}\infty\ ;t=0\\0\ ;t\neq0\end{cases}$ $\int_{-\infty}^{\infty}\delta(t)dt=1$

Note : Laplace transform of impulse response of a system is called transfer function.

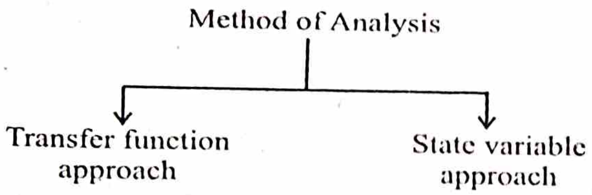
$$\boxed{L[\text{Impulse Response}]=\text{Transfer Function}}$$

- **Differentiation and integration of signals -**

$$\text{Parabolic response}\ \underset{\int}{\overset{\frac{d}{dt}}{\rightleftarrows}}\ \text{Ramp Response}$$

$$\text{Ramp Response}\ \underset{\int}{\overset{\frac{d}{dt}}{\rightleftarrows}}\ \text{Step Response}$$

$$\text{Step Response}\ \underset{\int}{\overset{\frac{d}{dt}}{\rightleftarrows}}\ \text{Impulse Response}$$



- **Advantages and disadvantage of transfer function**

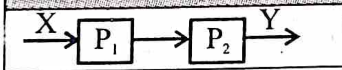
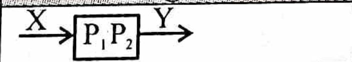
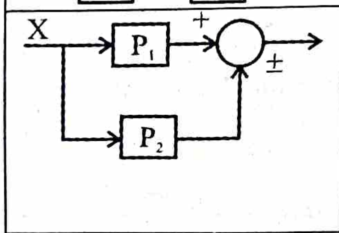
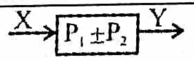
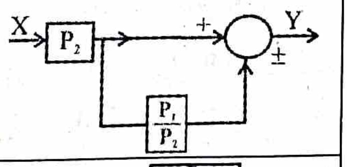
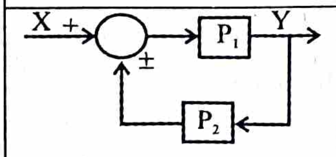
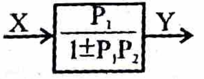
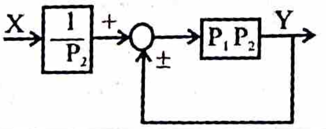
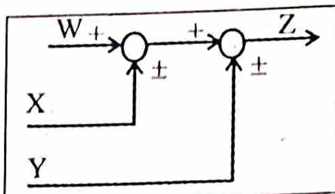
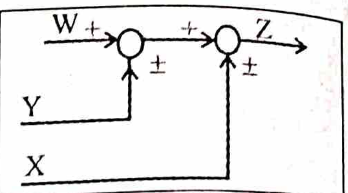
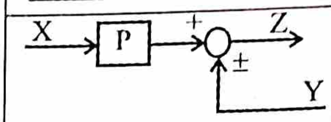
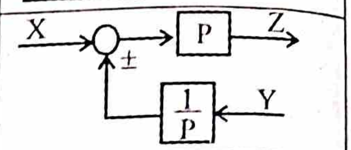
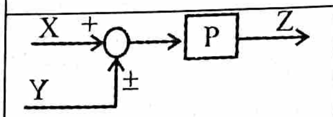
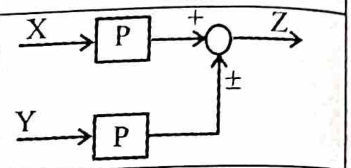
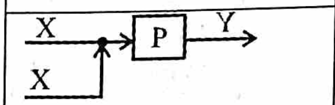
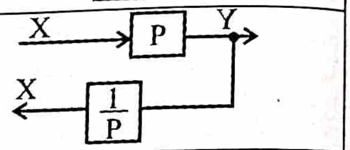
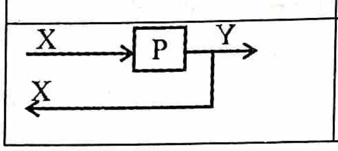
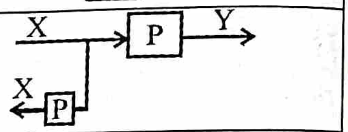
Advantages	Disadvantages
Output of the system can be easily determined.	Applicable only for linear time invariant system.
Poles and zeros of the system are directly identified.	Initial condition must be taken as zero.
Stability can be easily determined.	Applicable only for single input and single output.
Gives simple mathematical algebraic equation.	Controllability and observability cannot be determined, as in state variable approach.
Valid only for LTI system	Internal states of system cannot be determined.
	Valid only for SISO
	It does not describe internal state.
	This method gives only zero state response (ZSR)

➢ Example of transfer function method : Root locus, polar plot, Nyquist plot, Bode plot.

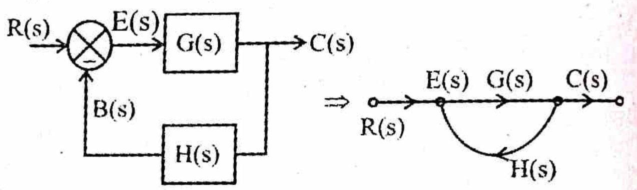
- **Advantages and disadvantage of state variable model.**

Advantages	Disadvantages
Valid for All System (i.e. LTI & Non LTI System)	State explosion problem
Gives both zero state response (ZSR) zero input response (ZIR)	

- **Block diagram**

Block diagram	Equivalent block diagram
	
	 
	 
	
	
	
	
	

❑ Signal flow graphs -

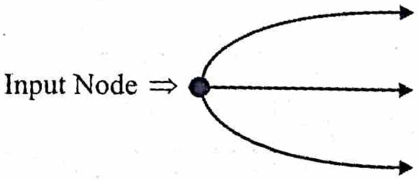


(Fig: Graphical representation of set of linear algebraic expressions.)

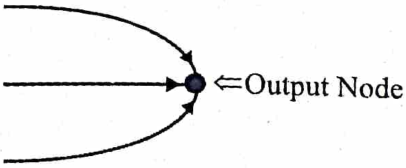
▣ **Terminology of S.F.G.'s:**

(i) **Node:** It represent system variable made is equal to a sum of all incoming signals at it.

(ii) **Input Node (Source Node):** It is node having only outgoing branches.



(iii) **Output node (Sink Node)-**It is node having only incoming branches.



(iv) **Mixed (Chain) Node:** It is a node having both incoming and output branch.

- **Mason's Gain Formula**

$$\boxed{\text{Transfer function} = \frac{\sum_{K=1}^{n} P_K \Delta_K}{\Delta}}$$

Where, n = Total number of forward path

P_K = Path gain of K^{th} forward path

Δ = 1– (Sum of gains of all individual loops) +(sum of gain products of all possible combination of two non-touching loops) – (sum of gain products of 3 non-touching loops) + ...

Δ_K = Value of Δ which is non-touching K^{th} forward path.

- **Limitation-**

➢ It is applicable only LTI system

➢ Mason's gain formula can only applicable to input and output.

➢ It is complicated to implement without making mistake, if signal flow graph consist many loop non-touching loops.

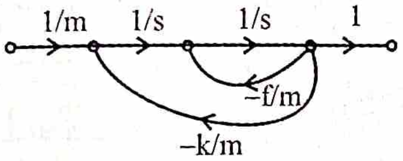
➢ Mason's gain not valid for self sustaining loop with unity gain.

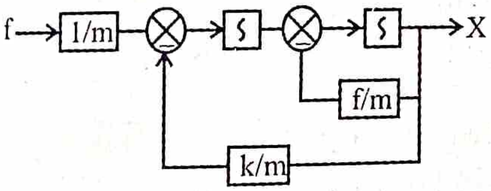
➢ At self loop with any gain at input is invalid.

- **State diagram -**

$$T.F.=\frac{\frac{1}{ms^2}}{1+\frac{f}{m}\left(\frac{1}{s}\right)+\frac{k}{ms^2}}$$

$$T.F=\frac{\left(\frac{1}{m}\right)/s^2}{1-\left\{-\frac{f}{ms}-\frac{k}{ms^2}\right\}}=\frac{P_1\Delta_1}{1-\{L_1+L_2\}}$$





■ **Sensitivity** = $\frac{\%\,\text{change in}\,\alpha}{\%\,\text{change in}\,\beta}=\frac{\beta}{\alpha}.\frac{d\alpha}{d\beta}$

$\alpha \rightarrow$ A variable that change its value.

$\beta \rightarrow$ A parameter that changes the value of 'α'

Sensitivity of closed loop system (CLCS)-

$$\boxed{S_G^T=\frac{\partial T/T}{\partial G/G}=\frac{G}{T}\frac{\partial T}{\partial G}}$$

$$\boxed{S_G^T=\frac{1}{1+G(s)H(s)}}$$

1+G(s) H(s) = Noise reduction or (Return difference).

Sensitivity of CLCS w.r.t disturbance H(s)-

$$S_{H(s)}^T=\frac{-G(s)H(s)}{1+G(s)H(s)}$$

Sensitivity of OLCS w.r.t disturbance in G(s)

$$\boxed{S_G^T=1}$$

➢ $\left(S_G^T\right)_{\text{closed loop}}<\left(S_G^T\right)_{\text{open loop}}$ (for negative feedback)

➢ Feedback can increase or decrease the sensitivity of a system.

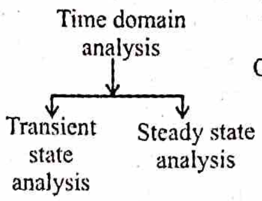
■ **Feedback characteristics of control system-**

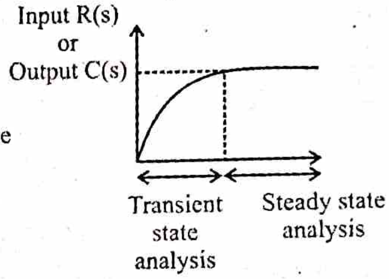
- **Effect of feedback-**

Positive feedback	**Negative feedback**
Gain increase with positive feedback $T.F.=\frac{G(s)}{1-G(s)H(s)}$	Gain decreases with negative feedback. $T.F.=\frac{G(s)}{1+G(s)H(s)}$
System stability will decreases.	System stability will increases.

❑ Time Domain analysis

Time response analysis is analysis on time taken by the response of system when subjected to an input.





➢ The transient response with feedback system decays quickly.

➢ The transient response of system is mainly due to stored energy.

- **Standard test signal-(Time domain analysis)**

Sudden shocks – impulse signal

Sudden type input – Step signal.

Velocity type input – Ramp signal

Acceleration type input – Parabolic signal.

- **Type and order-**

➢ Type of system obtained by open loop T.F observing the number of open loop poles occurring at origin.

➢ Transient state analysis depend open order of C.S.

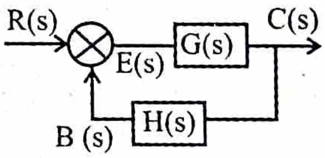
➢ Order of system obtained from closed loop T.F by observing the highest power of a control system equation.

➢ Steady state response analysis depends on type of the control system.

- **Steady state error (e_{ss})**

For unity feedback system,

Error ratio [E (s)] = $\frac{R(s)}{1+G(s)H(s)}$



Steady state error (e_{ss}) $\frac{\lim_{S\to 0} sR(s)}{1+\lim_{S\to 0} G(s)H(s)}$

Type	Step signal $\left(\frac{A}{s}\right)$	Ramp signal $\left(\frac{A}{s^2}\right)$	Parabolic signal $\left(\frac{A}{s^3}\right)$
0	$\frac{A}{1+K_p}$ $(K_p = k)$	∞ $(K_v = 0)$	∞ $(K_a = 0)$
1	0 $(K_p = \infty)$	$\frac{A}{K_V}$ $(K_v = k)$	∞ $(K_a = 0)$
2	0 $(K_p = \infty)$	0 $(K_v = k)$	$\frac{A}{K_a}$ $(K_a = k)$

Where,

- **Position error constant,** $K_p = \lim_{s\to 0} G(s)H(s)$
- **Velocity error constant,** $K_V = \lim_{s\to 0} sG(s)H(s)$
- **Acceleration error constant,**
  $K_a = \lim_{s\to 0} s^2 G(s)H(s)$
- **To find dynamic error constant:**

$$\left[\begin{array}{l} K_o = \lim_{x\to\infty} F(S) \\ K_1 = \lim_{s\to\infty} \frac{d}{ds} F(S) \\ K_2 = \lim_{s\to 0} \frac{d^2}{ds^2} F(S) \\ \text{where } F(S) = \frac{1}{1+G(S)} \end{array}\right]$$

➢ Relation b/w Static and Dynamic error constant

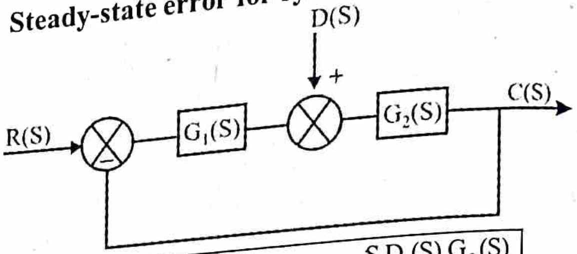
$$\boxed{K_o = \frac{1}{1+K_p}} \quad \boxed{K_1 = \frac{1}{K_V}} \quad \boxed{K_2 = \frac{1}{K_A}}$$

➢ If order of input > type of system → error (e_{ss}) infinite.

➢ If order of input < type of system → error (e_{ss}) zero.

➢ If type of system = order of system → error (e_{ss}) finite.

- **Steady-state error for systems with disturbance -**

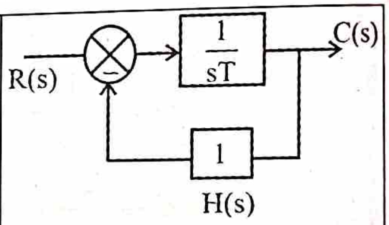


$$\boxed{e_{ss} = \lim_{S\to 0} \frac{S.R.(S)}{1+G_1(S)G_2(S)} - \lim_{S\to 0} \frac{S.D.(S).G_2(S)}{1+G_1(S)G_2(S)}}$$

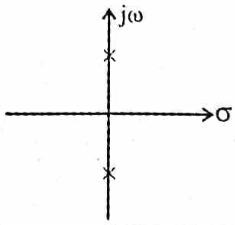
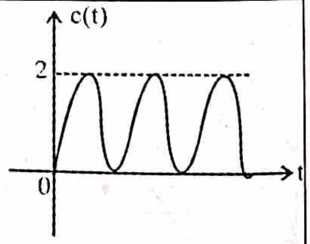
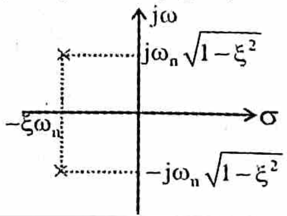
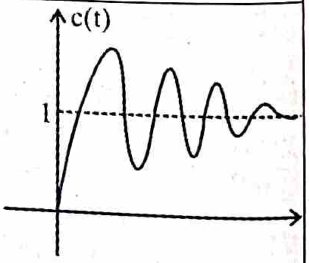
- **Transfer function of system**

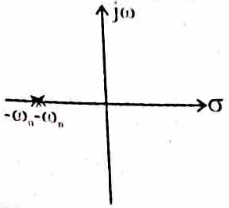
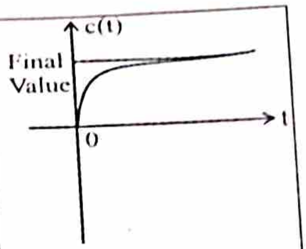
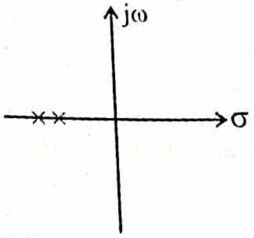
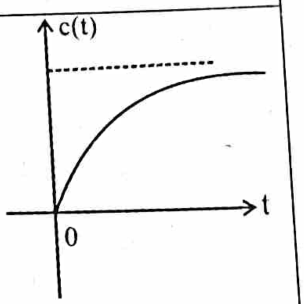
Zero order system	First order system	Second order system
$\frac{X_0(s)}{X_i(s)} = \frac{b_0}{a_0} = K$ $\boxed{T.F = K}$ **Ex-** Sensors and transducers	$\frac{X_0(s)}{X_i(s)} = \frac{b_0}{a_1 s + a_0}$ $\boxed{T.F = \frac{K}{1+Ts}}$ **Ex-**Thermal system, liquid level system etc.	$\boxed{T.F = \frac{\omega_n^2}{s^2 + 2\xi\omega_n s + \omega_n^2}}$ **Ex-** All indicating instruments, RLC network

- **First order system -**

$T.F = \frac{C(s)}{R(s)} = \frac{1}{sT+1}$ $C(s) = \frac{1}{sT+1}.R(s)$ For unit step response - $C(t) = 1 - e^{-t/T}$	

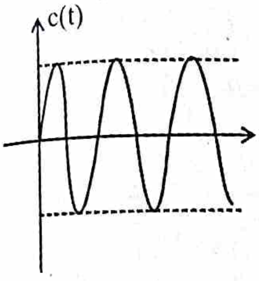
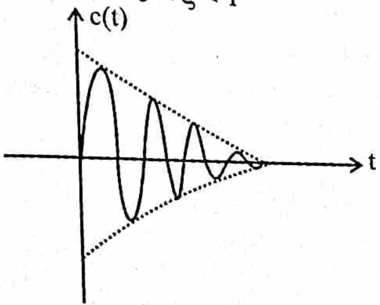
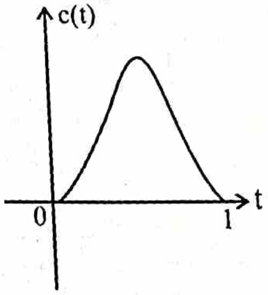
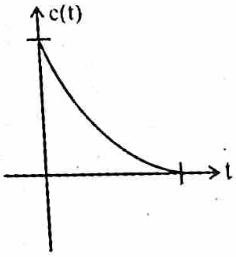
- **Second order system**

System	Step response (c(t))	Roots (Pole location)	Graph
Undamped $\xi = 0$	$c(t) = (1 - \cos\omega_n t)u(t)$	$s = \pm j\omega_n$ (imaginary) 	
Underdamped $0 < \xi < 1$	$c(t) = \left[1 - \frac{e^{-\xi\omega_n t}}{\sqrt{1-\xi^2}} \times \sin(\omega_d t + \theta)\right] u(t)$ Where $\theta = \cos^{-1}\xi$	$-\xi\omega_n \pm j\omega_n\sqrt{1-\xi^2}$ (Complex conjugate) 	

Critical damped $\xi = 1$	$c(t) = [1 - e^{-\omega_n t}(1+\omega_n t)]u(t)$	$-\omega_n, -\omega_n$ (Real and equal) 	
Overdamped $\xi > 1$	$c(t) = \left[1 - \dfrac{e^{-\left(\xi\omega_n - \omega_n\sqrt{\xi^2-1}\right)t}}{\left(2\sqrt{\xi^2-1}\right)\left(\xi-\sqrt{\xi^2-1}\right)}\right]u(t)$	$-\xi\omega_n \pm \omega_n\sqrt{\xi^2-1}$ (Real and unequal) 	

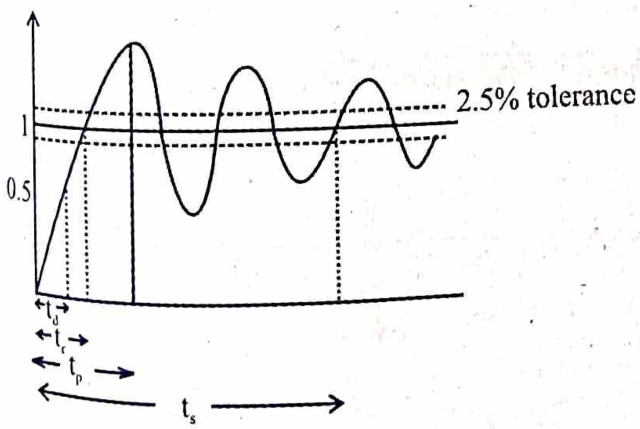
- Over damped gives slower response & critical gives faster for step unit although they look almost similar.

- **Second order system with impulse response -**

$\xi = 0$	$0 < \xi < 1$	$\xi = 1$	$\xi > 1$
 $c(t) = \omega_n \sin\omega_n t$	 $c(t) = \dfrac{\omega_n}{\sqrt{1-\xi^2}} e^{-\xi\omega_n t}\sin\omega_d t$	 $c(t) = \omega_n^2 t e^{-\omega_n t}$	

- **For under damped system ($\xi < 1$) -**

- $\cos\theta = \xi$
- Damping coefficient or actual damping $(\alpha) = \xi\omega_n$
- Time constant $(T) = \dfrac{1}{\alpha} = \dfrac{1}{\xi\omega_n}$
- Damped natural frequency $(\omega_d) = \omega_n\sqrt{1-\xi^2}$ .r/s
- Damping ratio $= \dfrac{\text{Actual damping}}{\text{Critical damping}} = \dfrac{\xi\omega_n}{\omega_n} = \xi$



- **Concept of Damping-**

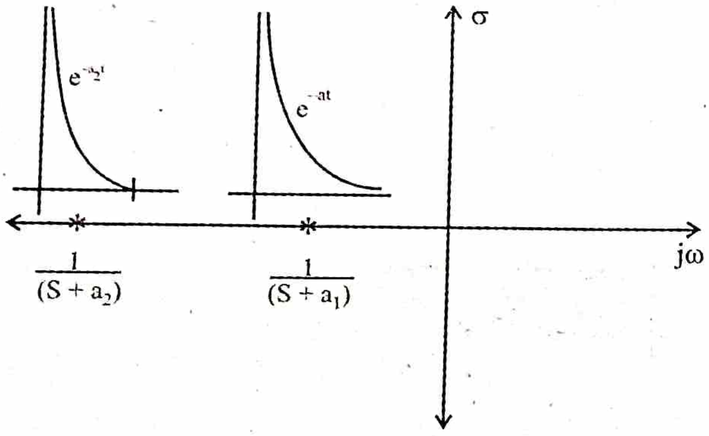
Damping ξ	**Series RLC** $\left\{\xi = \dfrac{R}{2}\sqrt{\dfrac{C}{L}}\right\}$	**Parallel RLC** $\left\{\xi = \dfrac{1}{2R}\sqrt{\dfrac{L}{C}}\right\}$.
Undamped $\xi = 0$	$R = 0$	$R = \infty$
Underdamped $0 < \xi < 1$	$0 < R < 2\sqrt{\dfrac{L}{C}}$	$\dfrac{1}{2}\sqrt{\dfrac{L}{C}} < R < \infty$
Critical damped $\xi = 1$	$R = 2\sqrt{\dfrac{L}{C}}$	$R = \dfrac{1}{2}\sqrt{\dfrac{L}{C}}$
Overdamped $\xi > 1$	$R > 2\sqrt{\dfrac{L}{C}}$	$R < \dfrac{1}{2}\sqrt{\dfrac{L}{C}}$

- **Time Response Specification**

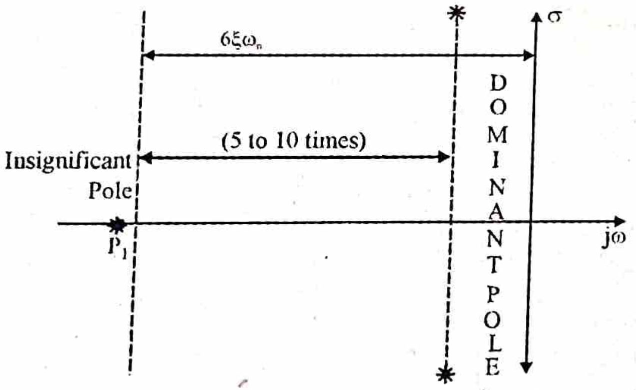
Time domain Parameter	**1st order**	**2nd order**
Delay time (t_d)	0.693τ	$(1+0.7\xi)/\omega_n$ (sec)
Rise time (t_r)	2.2τ	$(\pi-\theta)/\omega_d$ $\theta = \cos^{-1}(\xi)$ $\omega_d = \omega_n\sqrt{1-\xi^2}$

Peak time (t_p)	–	$(n\pi/\omega_d)$
% Maximum peak overshoot (M_p)	–	$e^{-\pi\cot\theta} = e^{-\xi\pi/\sqrt{1-\xi^2}} \times$ 100%
Settling time (t_s)	4τ	$4\tau = 4/\xi\omega_n$ (2% tolerance band) $3\tau = 3/\xi\omega_n$ (5% tolerance band)

- **Time-Response Analysis for higher order system:** The time response analysis of higher order system is approximated to 2nd order system or 1st order system with respect to dominant pole.
  When approximating a higher order transfer function to a lower order transfer function convert in time constant form and then eliminate insignificant pole.
  Consider a 3rd order characteristics equation
  $s^3 + Ps^2 + qs + k = 0$
  $(s + P_1)(s^2 + q_1 s + k_1) = 0$


$e^{-a_2 t}$
e^{-at}
σ
jω
$\frac{1}{(S+a_2)}$
$\frac{1}{(S+a_1)}$

- **Concept of Dominant pole**

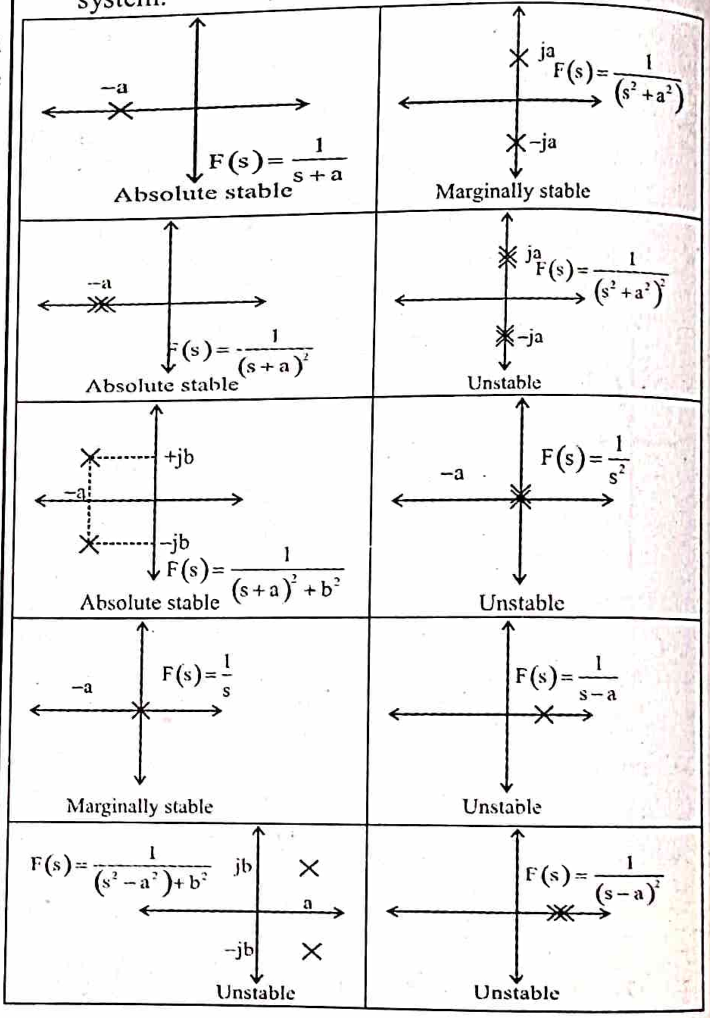

$6\xi\omega_n$
(5 to 10 times)
Insignificant Pole
P_1
DOMINANT POLE
σ
jω

For dominant pole- $\boxed{\frac{ISP}{SP} \ge 5 \text{ to } 10}$

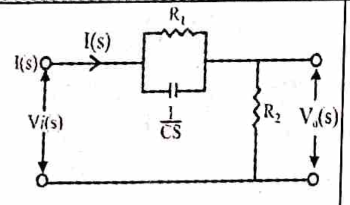
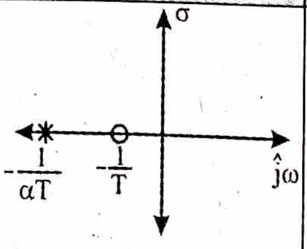
- ➢ Speed of dominant pole is least.
- ➢ Overall time constant is defined as $\left|\frac{1}{SP}\right|$.
- ➢ In dominant pole concept we neglect ISP.
- ➢ DC gain should be same approximately.

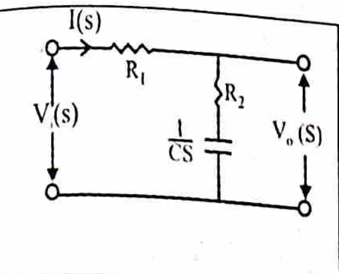
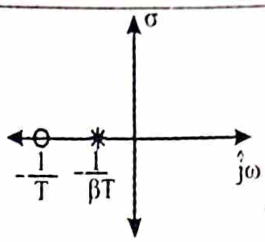
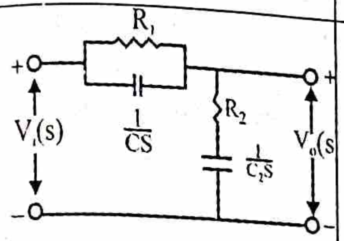
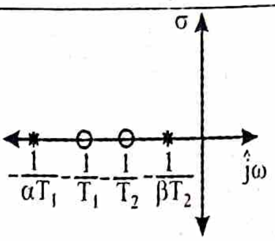
☐ Stability Analysis of Control System

Stability of closed loop system- Stability of closed loop system depends on roots of closed loop system.


−a
$F(s) = \frac{1}{s+a}$
Absolute stable
ja
$F(s) = \frac{1}{(s^2+a^2)}$
−ja
Marginally stable
−a
$F(s) = \frac{1}{(s+a)^2}$
Absolute stable
ja
$F(s) = \frac{1}{(s^2+a^2)^2}$
−ja
Unstable
+jb
−a
−jb
$F(s) = \frac{1}{(s+a)^2+b^2}$
Absolute stable
$F(s) = \frac{1}{s^2}$
−a
Unstable
$F(s) = \frac{1}{s}$
−a
Marginally stable
$F(s) = \frac{1}{s-a}$
Unstable
$F(s) = \frac{1}{(s^2-a^2)+b^2}$
jb
a
−jb
Unstable
$F(s) = \frac{1}{(s-a)^2}$
Unstable

☐ Compensators

Name	Circuit	Transfer function	Pole zero representatio	
Lead Compensator	 R_1 I(s) I(s) $V_i(s)$ $\frac{1}{CS}$ R_2 $V_o(s)$	$\frac{\alpha(1+TS)}{(1+\alpha TS)}$ $T = R_1C\,;\ \alpha = \frac{R_2}{R_1+R_2}$ $(\alpha < 1)$	 σ $-\frac{1}{\alpha T}$ $-\frac{1}{T}$ jω	Used for improve the transient state or speed of response **Act as** Adding a zero to a system transfer function

Lag Compensator		$\frac{(1+TS)}{(1+\beta TS)}$ $T=R_2C;\beta=\frac{1}{\alpha}=\frac{R_1+R_2}{R_2}$ $(\beta>1)$		**Used** for improving the steady-state characteristic. **Act as** Adding a pole to a system transfer function
Lag Lead Compensator	 R₁ + - V_i(S) 1/CS R₂ 1/C₂S V₀(s + -	$\frac{\alpha(1+T_1S)(1+T_2S)}{(1+\alpha T_1S)(1+\beta T_2S)}$ $\alpha=\frac{R_2}{R_1+R_2};\beta=\frac{R_1+R}{R_2}$ $T_1=R_1C_1;T_2=R_2C_2$		**Used** for improving both transient and steady-state response characteristic **Act as** Adding a pole and zero.

- Adding zero to a system TF in term of compensator represent lead compensation. It improves transient response.
- Adding a pole to TF will always represent a lag compensator.
- It improves steady state response.
- Lead compensators same to PD controller
- Lag compensator similar to PI controller
- Lag lead compensator similar to PID controller
- **Effect of Compensators**

Effect of Lead Compensator	Effect of lag compensator	Effect of lag-lead Compensator
Improves transient response. Increases the stability margin Increases bandwidth. $\left(\frac{S}{N}\right)_{output}<\left(\frac{S}{N}\right)_{input}$	Improves steady state response. Reduces the stability margin Decreases bandwidth Does not affect transient response.	Improve both steady state and transient response.

❑ Controller

Proportional Mode	Integral Mode	Derivative Mode
Also known as ON-OFF controller $K_p\uparrow$ $e_{ss}\downarrow$ $\xi\downarrow$ When $\xi<1$, % $M_P\uparrow$ The disadvantage of this controller is it exhibits a permanent residual error known as offset.	It increase type and order by one make the system less stable. Steady state error reduce It improve steady state response.	It is called tachometer feedback Also known as 'Rate controller' and anticipatory controller $\xi\uparrow$ $t_r\uparrow$ $e_{ss}\uparrow$ The disadvantage of this controller is it can not respond to sudden error. It is also called anticipatory controller. Type and order of the system reduced by one

Composite controller

Proportional Derivative controller	proportional Integral	P-I-D
Improves damping Reduce maximum overshoot Bandwidth ↑, $t_r\downarrow$ Improves gain Margin, Phase margin. Improve transient state response Similar to lead compensator It acts as high pass filter. It amplifies noise & Reduce S/N ratio. Increase stability of system.	Noise level reduces Reduce maximum overshoot $t_r\uparrow$ Bandwidth ↓ Improves GM, PM and M_r. Improve steady state response Eliminates offset of proportional controller. It is similar to lag compensator It acts as low pass filter. Increase type and order of system by one. Reduce the stability of the system.	Combined advantage of all three controller Band Reject filter. It increase type and order of the system by one

Time Domain Methods

Routh's criterion

Root Locus

- **Routh-Hurwitz Stability Criterion-**

- For system to be stable, coefficient of first column of Routh array made from its characteristic equation must have same sign.

- If first element of any row is zero while the rest of row has atleast one non-zero terms then in such cases substitute ε in place of zero and evaluate the rest of routh array in terms of ε and put lim ε → 0
- If system is not stable then number of sign change in first column of Routh tabulation is equal to the number of roots lies in right half of s-plane.
- Coefficient of ROZ (Row of Zeros) in R-H array

  $= \text{Coefficient of } \frac{d}{ds}A(s)$

  A(s) = Auxiliary polynominal
- For 3rd order system $(as^3 + bs^2 + cs + d = 0)$

Stable	IP > EP	bc > ad
Unstable	EP > IP	ad > bc
Marginal Stable	IP = EP	bc = ad

Where,

IP = Internal product, EP = External product.

☐ Root Locus

- Given by W.R. Evans
- Root locus is drawn with the help of spirule.
- Root locus determines relative stability of the system
- A point on real axis is said to be on RL if to the right side of this point the sum of open loop poles & zeros is odd.
- If stability increase then root locus shifts to LHS.
- Root locus is the best method for determining the stability and transient response.

Locus	Range of open loop gain
Root locus	K→0 to ∞
Complementary Root Locus	K→ 0 to − ∞
Complete Root Locus	K → − ∞ to ∞

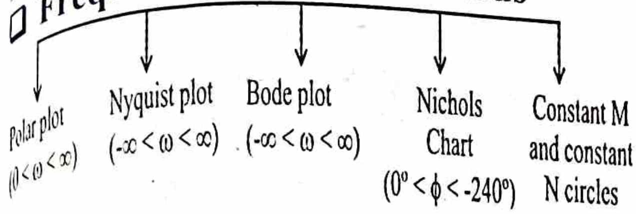
- **Construction rule of Root Locus**

Steps for Root Locus	Formula
	Root locus is symmetrical about real axis.
	When (P-Z) > 0 root locus drawn from open loop poles to the open loop zeros or infinity. The number of branches of root locus = P Number of branches terminating at zero = Z. Number of branches terminating at infinite = P − Z. Where; P= number of open poles Z = number of open zeros
Angle of asymptotes	Number of asymptotes = P − Z $\theta_A = \frac{(2q+1)\times180°}{(P-Z)}$ $\left\{\text{for complementary Root locus - } \theta_A = \frac{2q\times180°}{P-Z}\right\}$ Angle between asymptotes $= \frac{2\pi}{P-Z}$ Where; q = 0,1,2,3,..........
Centroid	$\sigma_A = \frac{\Sigma(\text{Real part of open loop poles})-\Sigma(\text{Real part of open loop zeros})}{\lvert P-Z\rvert}$ It is the intersection point of asymptotes on the real axis. It may are may not be a part of RL.
Break away or Break in point	They are those point where multiple roots of characteristics equation occurs. **Procedure for finding B.A point** (a) Construct 1 + G (S) H (S) = 0 (b) Write K in term of S. (c) Find $\frac{dk}{ds} = 0$ (d) The roots of $\frac{dk}{ds} = 0$ will be gives B.A. points.
Angle of departure or angle of arrival	$\phi_D = 180^0 + \phi$ and $\phi_A = 180^0 - \phi$ $\phi = \phi_z - \phi_p$ {ϕ_z = sum of all angle made by zero. ϕ_D = sum of all angle made by poles.}
Intersection of locus with imaginary axis	Root locus of the auxiliary equation at k=k$_{\text{marginal}}$ from Routh array gives intersection of locus with imaginary axis

Initial and final value theorem -

- Initial value $x_{t\to 0}(t)=\lim_{s\to\infty} s\,x(s)$
- It is valid for both stable and unstable system.
- Final value $x_{t\to\infty}(t)=\lim_{s\to 0} s\,x(s)$
- It is valid only for absolutely stable system.

Frequency Domain Methods


Polar plot
$(0<\omega<\infty)$
Nyquist plot
$(-\infty<\omega<\infty)$
Bode plot
$(-\infty<\omega<\infty)$
Nichols Chart
$(0^\circ<\phi<-240^\circ)$
Constant M and constant N circles

- **Frequency response analysis (2^{nd} - order)-**

Resonant frequency $(\omega_r)=\omega_n\sqrt{1-2\xi^2}$

Resonant peak $|M_r|=\dfrac{1}{2\xi\sqrt{1-\xi^2}}$

Phase angle at resonant frequency $(\phi_r)=$

$$-\tan^{-1}\left[\frac{\sqrt{1-2\xi^2}}{\xi}\right]$$

When $\xi\to 0$ then ω_n and $M_r\to\infty$

Phase Margin and Gain Margin -

GM	$GM=\dfrac{1}{\lvert G(j\omega)H(j\omega)\rvert_{\omega=\omega_{pc}}}$ in dB, $GM=-20\log[G(j\omega)H(j\omega)]$	GM = +ve {for stable system}
PM	$PM=180^\circ+\angle G(j\omega)H(j\omega)\rvert_{\omega=\omega_{gc}}$	PM = +ve{for stable system} $\omega_{pc}>\omega_{gc}$

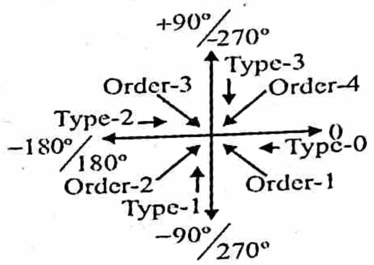
Polar plot

- **Magnitude**

$|G(j\omega)H(j\omega)|\Rightarrow$ put $s=j\omega$ then $|a+jb|=\sqrt{a^2+b^2}$

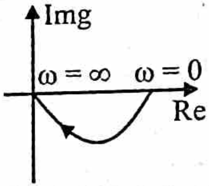
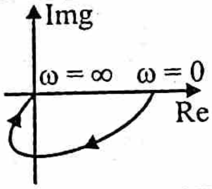
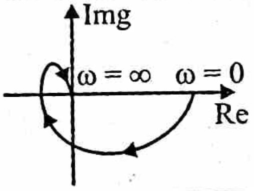
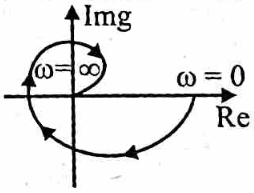
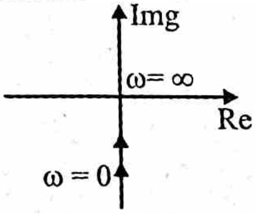
- **Phase angle**

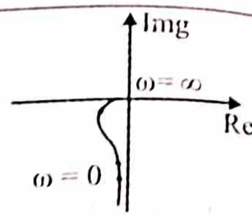
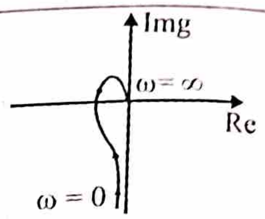
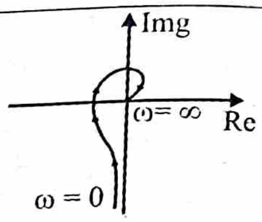
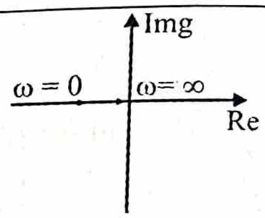
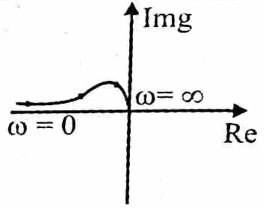
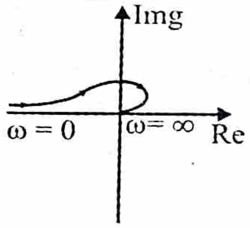
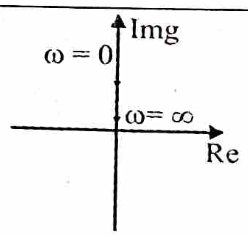
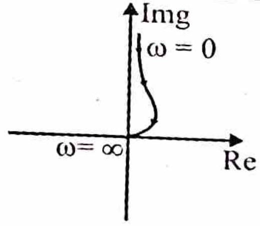
$\angle G(j\omega)H(j\omega)\Rightarrow$ put $s=j\omega$ then $\angle(a+jb)=\tan^{-1}b/a$


+90°/-270°
Type-3
Order-3
Order-4
Type-2
−180°/180°
0
Type-0
Order-2
Order-1
Type-1
−90°/270°

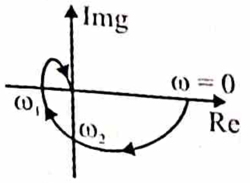
- **Shapes of Polar Plot**

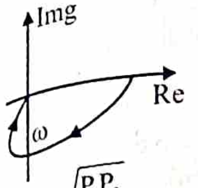
Shapes of Polar Plot

Type and Order	Transfer function	Polar plot
Type-0 Order-1	$G(s)=\dfrac{1}{1+Ts}$	
Type-0 Order-2	$G(s)=\dfrac{1}{(1+T_1s)(1+T_2s)}$	
Type-0 Order-3	$G(s)=\dfrac{1}{(1+T_1s)(1+T_2s)(1+T_3s)}$	
Type-0 Order-4	$G(s)=\dfrac{1}{(1+T_1s)(1+T_2s)(1+T_3s)(1+T_4s)}$	
Type-1 Order-1	$G(s)=\dfrac{1}{s}$	

Type-1 **Order-2**	$G(s)=\frac{1}{s(1+Ts)}$	
Type-1 **Order-3**	$G(s)=\frac{1}{s(1+T_1s)(1+T_2s)}$	
Type-1 **Order-4**	$G(s)=\frac{1}{s(1+T_1s)(1+T_2s)(1+T_3s)}$	
Type-2 **Order-2**	$G(s)=\frac{1}{s^2}$	
Type-2 **Order-3**	$G(s)=\frac{1}{s^2(1+Ts)}$	
Type-2 **Order-4**	$G(s)=\frac{1}{s^2(1+T_1s)(1+T_2s)}$	
Type-3 **Order-3**	$G(s)=\frac{1}{s^3}$	
Type-3 **Order-4**	$G(s)=\frac{1}{s^3(1+Ts)}$	

- **Value of cutting frequency -**

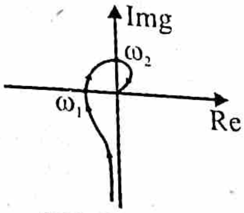

Img
ω = 0
ω₁
ω₂
Re

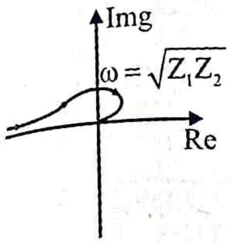


$\omega = \sqrt{P_1P_2}$

$$\omega_1 = \sqrt{P_1P_2 + P_2P_3 + P_3P_1}$$

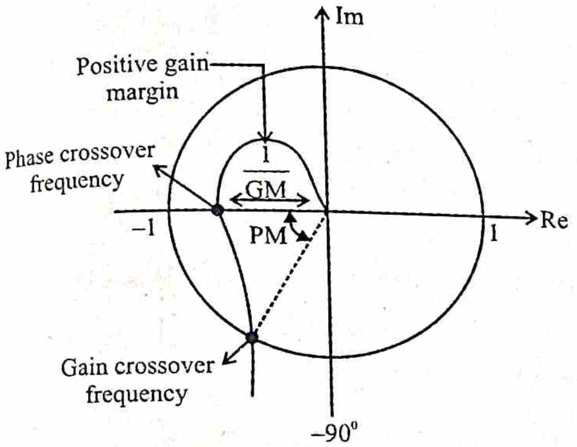
$$\omega_2 = \sqrt{\frac{P_1P_2P_3}{P_1+P_2+P_3}}$$




Img
ω = √(Z₁Z₂)
Re

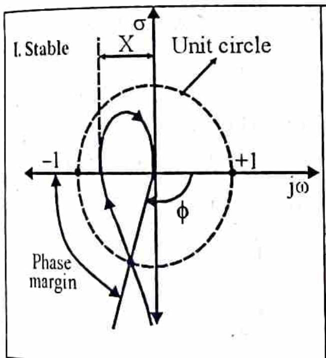
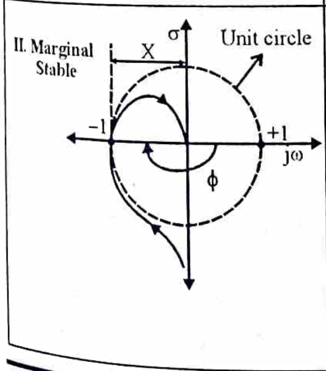
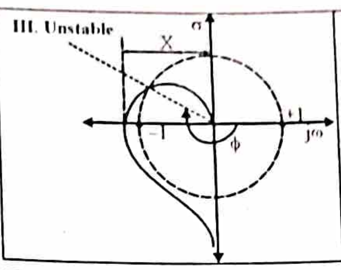
$$\omega_1 = \sqrt{Z_1Z_2 + Z_2Z_3 + Z_3Z_1}$$

$$\omega_2 = \sqrt{\frac{Z_1Z_2Z_3}{Z_1+Z_2+Z_3}}$$


Im
Positive gain margin
Phase crossover frequency
1/GM
GM
−1
PM
1
Re
Gain crossover frequency
−90°

Stable system

- **Stability from Polar plots–**

 I. Stable σ X Unit circle -1 +1 jω ϕ Phase margin	Gain margin $(GM) = \frac{1}{X}$ $GM(dB) = 20\log\frac{1}{x}$ Phase margin = $\phi - (-180)°$ $= \phi + 180$ = Positive
 II. Marginal Stable σ X Unit circle -1 +1 jω ϕ	x = 1 Gain margin $(GM) = \frac{1}{x} = 1$ G.M. (dB) = 20 log 1 = 0 dB $\phi = -180$ P.M. = 180 − 180 = 0
 III. Unstable σ X -1 +1 jω ϕ	Gain Margin = $\frac{1}{X}$ G.M. (dB) = $20\log\left(\frac{1}{X}\right)$ = negative P.M = negative

❑ Nyquist plot

■ Nyquist stability criteria $\boxed{N = P - Z}$

P = Number of open loop poles in RHS of s-plane

Z = Number of closed loop poles in RHS of s-plane.

N = Number of encirclements around (−1+j0) of GH plane (anticlockwise encirclement taken as positive).

For system to be stable Z = 0 and N = P

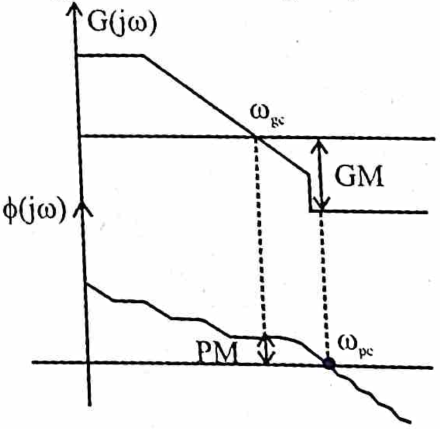
❑ Bode plot

Factor	Cut off frequency	Magnitude	Slope in (dB/dec)
k	–	20 log k	0
$(\hat{j}\omega)^{\pm n}$	–	± n×20log ω	± 20 × n
$(1+\hat{j}\omega)^{\pm 1}$	$\frac{1}{T}$	± 20 logωT	± 20
$\left(1+\left(\frac{\omega}{\omega_n}\right)^2+\hat{j}2\left(\frac{\omega}{\omega_n}\right)^2\right)$	ωₙ	± 40 log (ω/ωₙ)	± 40

$$|M|_{dB} = 20\log K = \left|G(j\omega)H(j\omega)\right|_{\omega=1\,rad/sec}$$

- ➢ Initial slope = 20 log K ± n log ω_1.
- ➢ K is always calculated from low frequency region.
- ➢ Slope = $\frac{d|M|_{dB}}{d\log\omega}$ dB/decade
- ➢ If n poles at origin then initial slope = -20n dB/dec
  And Phase angle $\angle\phi = -90n^0$
- ➢ If n zeros at origin then initial slope = +20n dB/dec
  And Phase angle $\angle\phi = +90n^0$
- ➢ 6dB/octave = 20 dB/decade
- ➢ Initial slope 0 dB/decade for underdamped system.
- ➢ Bode plot is not defined for undamped system (ξ=0).

- **Phase margin and Gain margin by Bode plot -**


G(jω)
ω_gc
GM
ϕ(jω)
PM
ω_pc

If $|G(j\omega)H(j\omega)|_{\omega=\omega pc} = 1$ → marginally stable

If $|G(j\omega)H(j\omega)|_{\omega=\omega pc} > 1$ → unstable

If $|G(j\omega)H(j\omega)|_{\omega=\omega pc} < 1$ → stable

and if, PM = Positive → stable
PM = Negative → unstable
PM = Zero → Marginally stable

- **Nicolas Chart-** It consist of magnitude and phase angles of a closed loop system represented as a family of circle known as M & N circles.

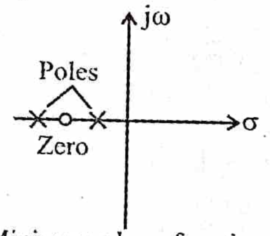
- **Constant M-circles and constant N-circles**

M-circles	N-circles
Radius $= \frac{M}{1-M^2}$	Radius $= \sqrt{\frac{1}{4}+\frac{1}{4N^2}}$
Centre $= \left(\frac{M^2}{1-M^2}, 0\right)$	Centre $= \left(\frac{-1}{2}, \frac{1}{2N}\right)$

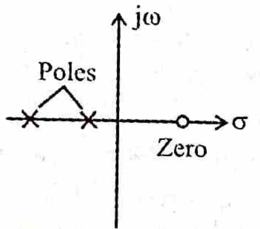
- ➢ $N = \tan\phi$

- **Minimum and Non-minimum phase system-** A transfer function is said to be minimum phase if it all poles and zeros are in the left half of the s-plane.

A transfer function is said to be non-minimum phase if one or more zeros present in the right half of s-plane.

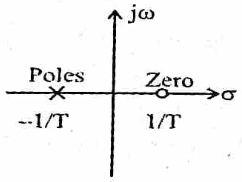

jω
Poles
Zero
σ

Minimum phase function


jω
Poles
Zero
σ

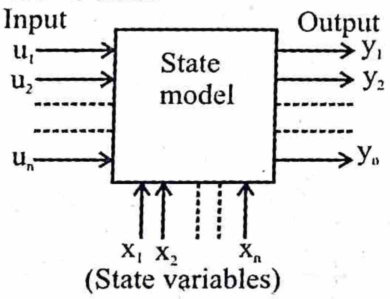
Non-minimum phase function

- **All pass system-** It is system in which zeros lies on R-H of s-plane, poles lies on L-H of s-plane and symmetrical about imaginary axis. For all pass system magnitude and phase angle is 1 and -180^0 respectively.


jω
Poles
Zero
σ
-1/T
1/T

☐ State space analysis

- **State space variable-**

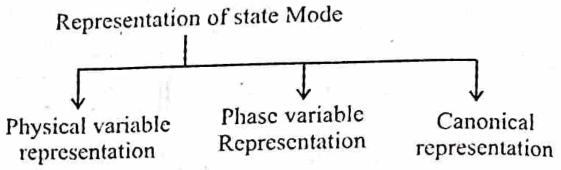
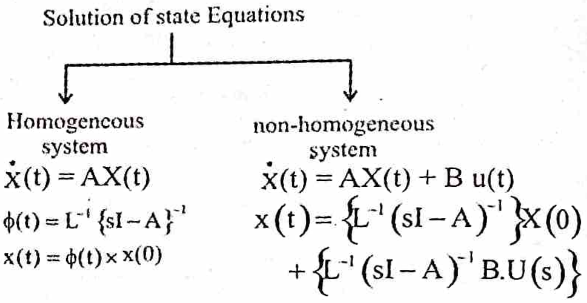

Input
Output
u_1
u_2
u_n
State model
y_1
y_2
y_n
x_1 x_2 x_n
(State variables)

$A = n \times n$
$B = n \times m$
$C = p \times n$
$D = p \times m$

State equation $\dot{X}(t) = Ax(t) + Bu(t)$

Output equation-

$Y = cx(t) + Du(t)$

- **Advantages of state Variable Approach**
- ➢ Applicable for linear, non-linear, time variant or time invariant system.
- ➢ Consider initial conditions.
- ➢ Internal states of the system can be determined
- ➢ Applicable for multiple input multiple output (MIMO) system.
- ➢ Controllability and observability can be determined.
- 
Representation of state Mode
Physical variable representation
Phase variable Representation
Canonical representation
- 
Solution of state Equations
Homogeneous system
non-homogeneous system

$\dot{x}(t) = AX(t)$

$\phi(t) = L^{-1}\{sI-A\}^{-1}$

$x(t) = \phi(t) \times x(0)$

$\dot{x}(t) = AX(t) + B\,u(t)$

$x(t) = \{L^{-1}(sI-A)^{-1}\}X(0) + \{L^{-1}(sI-A)^{-1}B.U(s)\}$

- ➢ Transfer function, T.F $= C[sI-A]^{-1}B + D$
- ➢ State transition matrix (STM)

$e^{At} = \phi(t) = L^{-1}\left[(sI-A)^{-1}\right]$

- ➢ Properties of state transition matrix

$\phi(0) = I$ (identity matrix), $\phi^{-1}(t) = \phi(-t)$

$[\phi(t)]^K = \phi(Kt)$ $\qquad \phi(t_1+t_2) = \phi(t_1)\phi(t_2)$

$\phi(t_2-t_1)\phi(t_1-t_0) = \phi(t_2-t_0)$

- **Controllability and observability-**

Controllability (Control space variable)	Observability (Measure state variables)
$\dot{X}(t) = AX(t) + Bu(t)$ $Q_c = [B : AB : A^2B : \dots A^{n-1}B]$ According to kalman's Test: System is controllable if Rank of Qc = order of system $\text{Det}: Q_c \neq 0$	$Y(t) = CX(t) + Du(t)$ $Q_o = [C^T : A^TC^T : (A^T)^2C^T \dots (A^T)^{n-1}C^T]$ System is observable if (Rank of Q_o = order of system) $\text{Det}: Q_o \neq 0$

- ➢ If AC is observable then A^TC^T is controllable.
- ➢ If AB is controllable then A^TB^T is observable.

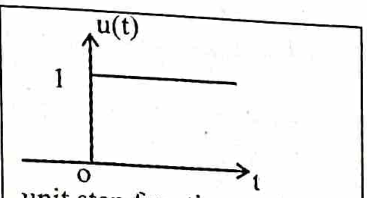
SIGNAL AND SYSTEM

Signal	A signal is function representing a physical quantity or variable, and typically it contains information about the behaviour or nature of the phenomenon.
System	System is a medium which process a signal. It converts signal one form to another form.

❑ Basic continuous-time signals

a. **The unit step Function** The unit step function u(t) also known as the Heaviside unit function, is defined as

$$u(t)=\begin{cases}1 & t>0\\ 1/2 & t=0\\ 0 & t<0\end{cases}$$

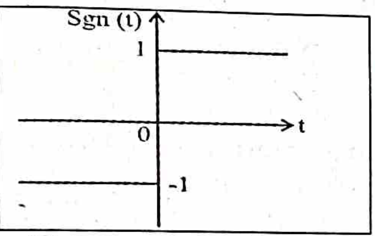


unit step function

- **Properties of Unit-step function**
  - $u(t)+u(-t)=1$, ➢ $u(t)-u(-t)=$ signum function
  - $u(t)=\dfrac{1+\text{sgn}(t)}{2}$
  - u(t) is a power signal

b. **Signum function**

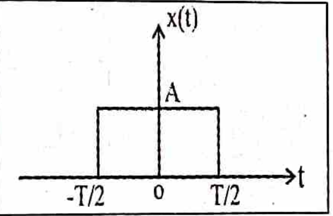
$$\text{Sgn}(t)=\begin{cases}1 & t>0\\ 0 & t=0\\ -1 & t<0\end{cases}$$



c. **Rectangular Function/Gate function**

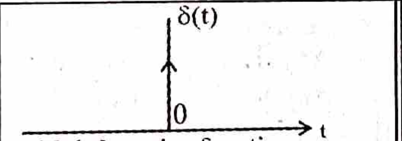
$$x(t)=A\,\text{rect}\left(\frac{t}{T}\right)$$

$$x(t)=\begin{cases}A & \dfrac{-T}{2}<t<\dfrac{T}{2}\\ 0 & \text{elsewhere}\end{cases}$$



d. **The unit impulse function/Dirac delta function**

$$\delta(t)=\begin{cases}\infty & t=0\\ 0 & \text{otherwise}\end{cases}$$



Unit Impulse function

- **Properties of impulse function**
  - Area under impulse function is 1 $\boxed{\int_{-\infty}^{\infty}\delta(t)\,dt=1}$
  - Impulse function is even function for all time $\boxed{\delta(t)=\delta(-t)}$
  - Scaling properties : $\delta(at)=\dfrac{1}{|a|}\delta(t)$
  - $f(t)\delta(t)=f(0)\delta(t)$ ➢ $f(t)\delta(t-a)=f(a)\delta(t-a)$
  - $\int_{-\infty}^{\infty}f(t)\delta(t)dt=f(0)$ ➢ $\int_{-\infty}^{\infty}f(t)\delta(t-a)dt=f(a)$

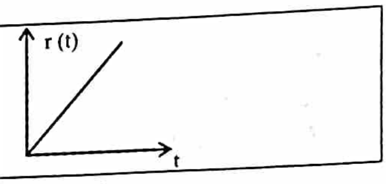
e. **Doublet Function**

First derivative of impulse function is called doublet function

- **Properties of unit doublet function**
  - $\delta'(t)=\dfrac{d\delta(t)}{dt}$, $\qquad \delta'(at)=\dfrac{1}{a|a|}\delta'(t)$
  - All even derivatives of $\delta(t)$ are even functions of time while all odd derivatives are odd functions.
  - If f(t) is any function, then $f(t)\delta'(t-a)=f(a)\delta'(t-a)-f'(a)\delta(t-a)$
  - $\int_{-\infty}^{\infty}f(t)\delta'(t-a)=\left.\dfrac{-df(t)}{dt}\right|_{t=a}$

f. **Ramp Signal**

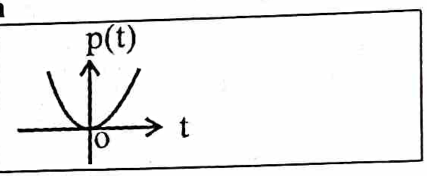
$$r(t)=\begin{Bmatrix}t & t\ge 0\\ 0 & t<0\end{Bmatrix}$$



- $r(t)=t\,u(t)$, $r(at)=a\,r(t)$, $\dfrac{d}{dt}r(t)=u(t)$

g. **Parabolic function**

$$p(t)=\begin{cases}\dfrac{t^2}{2} & t\ge 0\\ 0 & t<0\end{cases}$$



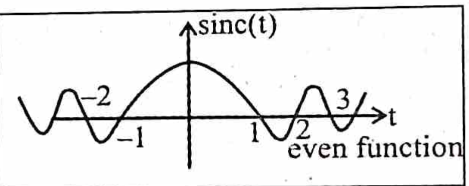
- $\boxed{\dfrac{d^3p(t)}{dt^3}=\dfrac{d^2r(t)}{dt^2}=\dfrac{du(t)}{dt}=\delta(t)}$

h. **Sinc function**

$$\text{sinc}(t)=\frac{\sin\pi t}{\pi t}$$

Area [sinc(t)] = 1

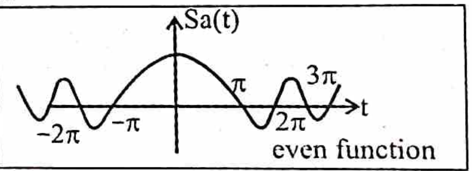
Energy [sinc(t)] = 1



i. **Sampling function**

$$Sa(t)=\frac{\sin t}{t}$$

$$Sa(\pi t)=\text{sinc}(t)$$

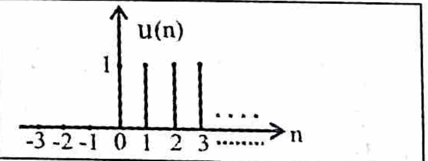


❑ Basic Discrete-time signals

a. **The unit step sequence**

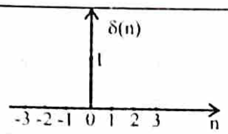
The unit step sequence u(n) is defined as

$$u(n)=\begin{cases}1 & n\ge 0\\ 0 & n<0\end{cases},$$



- $\begin{bmatrix}u(n)+u(-n)=1+\delta(n), & n=0\\ 1 & n\ne 0\end{bmatrix}$

- **The Unit impulse sequence**

$\delta(n)=\begin{cases}1 & n=0\\ 0 & n\neq 0\end{cases};$	

- **Properties of Discrete time impulse**

i. Discrete time impulse is an even function of time
$\delta[n]=\delta[-n]$

ii. Scaling property
$\delta[mn]=\delta[n]$

- The scaling property does not exist in discrete time impulse function because it depends on the amplitude.

iii. Product property:
(i) $x[n]\,\delta[n]=x(0)\,\delta[n]$
(ii) $x[n]\,\delta[n-n_0]=x[n_0]\,\delta[n-n_0]$

iv. $\sum_{n=-\infty}^{\infty}x[n]\delta[n-n_0]=x[n_0]$

$\sum_{n=n_1}^{n_2}x[n]\delta[n-n_0]=x[n_0]\quad n_1\le n_0\le n_2$

❑ Classification of signal

a. Energy and power signal

Energy	**Power**
For continuous time $E=\int_{-\infty}^{\infty}\lvert x(t)\rvert^2dt$	$\text{Power}=\begin{cases}\lim\limits_{T\to\infty}\frac{1}{2T}\int_{-T}^{T}\lvert x(t)\rvert^2dt;\text{for periodic signal}\\ \lim\limits_{T\to\infty}\frac{1}{T}\int_{-T/2}^{T/2}x(t)^2dt;\text{for non periodic signal}\end{cases}$
For discrete time $Ex(n)=\sum_{n=-\infty}^{\infty}\lvert x(n)\rvert^2$	$P_{avg}\,x(n)=\lim\limits_{N\to\infty}\frac{1}{2N+1}\sum_{n=-N}^{N}\lvert x(n)\rvert^2$
Energy = Finite, Power = 0	Energy = ∞, Power = Finite

-

Signal	**Area**	**Energy**
$x(t)=\sin c(t)$	1	1
$x(t)=\pi t^2$	1	$1/\sqrt{2}$
$x(t)=A\,\text{rect}\left(\frac{t}{\tau}\right)$	$A\tau$	$A^2\tau$
$x(t)=A\,\text{tri}\left(\frac{t}{\tau}\right)$	$A\tau$	$\frac{2}{3}A^2\tau$
$x(t)=e^{-at}u(t)$	$\frac{1}{a}$	$\frac{1}{2a}$
$x(t)=\text{sgn}(t)$	0	$1/a$

- For an energy signal the average power is zero
- For a power signal the energy is ∞.
- The frequency & phase of the signal will not effect the power calculations.

➢ Energy/Power calculation is independent of time shifting, time reversal and amplitude reversal.

➢ Power signal is also known as ''means square value of signal.''

$\boxed{\text{Power}=(\text{R.M.S.})^2}$

➢ If $x(t)\to$ Energy signal (E), Then- $x(at)\to\frac{E}{|a|}$

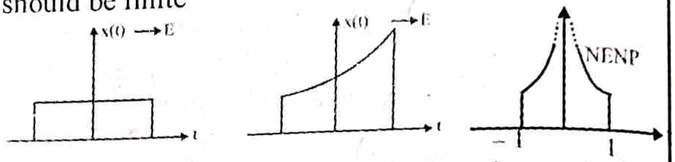
$x(t-t_0)\to E,\ x(-t)\to E$

$Ax(t)\to|A|^2E$

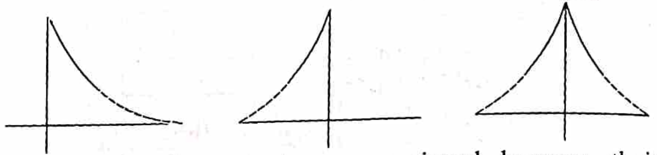
•Signal Identification:

Energy signal

For finite duration of energy signal, magnitude of signal should be finite



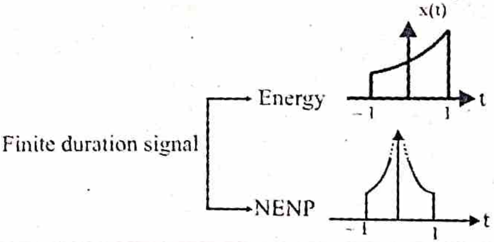
For infinite extension energy signal, peak magnitude of signal should be either left side or right side or both sided decreasing in nature. (From a finite value)



Periodic signal are not energy signal because their energy contains is infinite.

Periodic signal
→ Power ; sint
→ NENP ; tant

Infinite extension signal
→ Energy ; $e^{-2t}u(t)$
→ Power ; u(t)
→ NENP ; $\frac{1}{t}$



b. Even & odd Signal

- Even signal : $f(-t)=f(t)$ • Odd signal: $f(-t)=-f(t)$
- Any signal can be divided into two part in which one part will be even signal ($f_e(t)$) and other part will be odd signal ($f_0(t)$).
  i.e., $f(t)=f_e(t)+f_0(t)$,

➢ $f_0(t)=\frac{f(t)-f(-t)}{2}$ ➢ $f_e(t)=\frac{f(t)+f(-t)}{2}$

➢ Even × Even = Even , ➢ Odd × Odd = Even

➢ Odd × Even = Odd

➢ For even signal $=\int_{-a}^{a}f(t)dt=2\int_{0}^{a}f(t)dt$

➢ For Odd signal $=\int_{-a}^{a}f(t)dt=0$

➢ Derivative of even signal = Odd signal

➢ Derivative of Odd signal = even signal

➢ Integral of Odd signal = even signal

- **Conjugate symmetric (CS) and conjugate anti-symmetric (CAS) signal**

CS Signal $\boxed{x(t) = x^*(-t)}$

CAS Signal $\boxed{x(t) = x^*(-t)}$

Any signal can be divided into two part in which one part will be C.S. and other part will be conjugate A.C.

i.e. $x(t) = x_{CS}(t) + x_{CAS}(t)$

where,

$$\left(\begin{array}{l} x_{CA(t)} = \dfrac{x(t) + x^*(-t)}{2} \\ x_{CAS(t)} = \dfrac{x(t) - x^*(-t)}{2} \end{array} \right)$$

C.S.
- Complex ⇒ R + jI (Odd Signal, Even Signal)
- Real (R) ⇒ Odd Signal
- Imagniary (I) ⇒ Even Signal

C.A.S.
- Complex ⇒ R + jI (Odd Signal, Even Signal)
- Real (R) ⇒ Odd Signal
- Imaginary ⇒ Even Signal

Periodic and Non-periodic signal

- **Periodic and Non-periodic signal a periodic signal**

A signal is said to be periodic if it repeat itself after sometime.

i.e. $\boxed{x(t) = x(t \pm nT_o)}$ where n = 1, 2, 3.......

T_o = fundamental Time Period (FTP)

$\neq 0$

$\neq \infty$

- **Fundamental Time Period (FTP):** It is smallest positive volume of time for which signal is periodic.

$\boxed{T_o = \dfrac{2\pi}{W}}$ for sinωt, cosωt,

Notes: Fundamental time period calculation depends upon only scaling.

$$\boxed{\begin{array}{l} x(t) \xrightarrow{\text{FTP}} T_O \\ \text{i.e. } x(at) \longrightarrow \dfrac{T_O}{|a|} \\ a \neq 0 \end{array}}$$

- **Steps for finding the fundamental period of the signal**

$x(t) = x_1(t) + x_2(t) + x_3(t)$........

- Identify the individual periods (T_1, T_2, T_3.....)
- Calculate the ratio of $\dfrac{T_1}{T_2}, \dfrac{T_1}{T_3}, \dfrac{T_1}{T_4}$.........
- If the ratio is rational number
  Period (T)= LCM of [T_1,T_2,T_3.........]
- For discrete time signal –

$$\frac{N}{K} = \frac{2\pi}{\omega_0}$$

c. **Causal, anti causal and Non-causal signal**

- **Causal Signal-** A signal is said to be causal if it is defined for only positive value.

$\boxed{x(t) = 0,\ t < 0}$ $x[n] = 0,\ n<0$

- **Anti causal Signal** A continuous time signal x(t) is said to be anti causal-
  If $x(t) = 0 \quad t > 0, \quad x(n) = 0, \quad n \geq 0$
- **Non causal Signal** A signal which exists both positive and negative time is said to be non-causal signal.
- **Area of signal**

Area of signal x (t) = $\int_{-\infty}^{\infty} x(t)\,dt$

Area of signal over range (t_1, t_2)

$= \int_{t_1}^{t_2} x(t)\,dt$ per period signal

- **Average of signal**

➢ $\dfrac{1}{T}\int x(t)dt$; for periodic signal

➢ $\lim\limits_{T\to\infty} \dfrac{1}{T} \int_{-T/2}^{T/2} x(t)$; for non-periodic signal

$$\boxed{\text{Average} = \frac{\text{Area}}{\text{Time - Period}}}$$

➢ Average value also called 'D.C. Value'

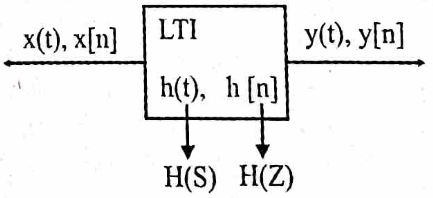
➢ Average calculation only depends upon Amplitude scaling and amplitude shifting

Signal	Average
$f(t)$	$\rightarrow A_o$
$kf(t)$	$\rightarrow kA_o$

➢ For finite duration signal having finite amplitude, average value is zero.

❑ Linear Time Invariant Systems •

LTI System–When any system follows two basic properties i.e. linearity and time-invariance are known as LTI system.



y (t) = x (t) * h (t)
Y (s) = X (s) .H (t)

y [n] = x [n] * h [n]
Y [z] = X [z] . H [z]

$\boxed{H(s) = \dfrac{Y(S)}{X(S)}}$

Transfer function

$\boxed{H(Z) = \dfrac{Y(Z)}{X(Z)}}$

Transfer function

■ Classification of systems

i. **Linear systems and Non- Linear systems** A system that obeys the superposition and homogeneity principle is said to be linear system, else non linear system.

- Superposition (Additivity)
  If $x_1(t) \rightarrow y_1(t)$, $x_2(t) \rightarrow y_2(t)$
  Then $x_1(t) + x_2(t) \rightarrow y_1(t) + y_2(t)$
- Homogeneity (scaling)
  $ax_1(t) + bx_2(t) \rightarrow ay_1(t) + by_2(t)$

- **Some Examples-**

System	System Nature	System	System Nature
$y(t) = x(\ell nt)$	Linear	$y(t) = e^{t} x(\ell nt)$	Linear
$y(t) = x(e^{t})$	Linear	$y(t) = x^{k}(t)$	Non-Linear
$y(t) = x(\sin t)$	Linear	$y(t) = x(t) + k$	Non-Linear
$y(t) = x(\lvert t \rvert)$	Linear	$y(t) = \sin\{x(t)\}$	Non-Linear
$y(t) = x(t^{2})$	Linear	$y(t) = e^{x(t)}$	Non-Linear
$y(t) = \sin t \, x(t)$	Linear	$y(t) = \lvert x(t) \rvert$	Non-Linear
$y(t) = \ell nt\{x(t)\}$	Linear	$y(t) = [x(t)]^{1/4}$	Non-Linear
$y(t) = t^{2} x(t)$	Linear	$y(t) = \mathrm{sgn}\{x(t)\}$	Non-Linear

ii. **Time-Invariant and time variant systems-** A system is called time-invariant if a time shift in the input signal causes the same time- shift in the output signal.

If $x(t) \to y(t)$, then $x(t - t_0) \to y(t - t_0)$

System	System Nature	System	System Nature
$y(t)= tx(t)$	T.V.	$y(t) = \mathrm{Re}\{x(t)\}$	T.V.
$y(t) = x(-t)$	T.V.	$y(t) = \mathrm{Im}\{x(t)\}$	T.I.V.
$y[n]= x[2n]$	T.V.	$y(t) = \frac{d}{dt}x(t)$	T.I.V.
$y(t) = x[\sin(t)]$	T.V.	$y[n] = x[n]-x[n-1]$	T.I.V.
$y(t) = 2t + x(t)$	T.V.	$y(t) = \int_{-\infty}^{t} x(3\tau)d\tau$	T.V.
$y(t) = e^{-t}x(t+2)$	T.V.	$y(t) = \int_{-\infty}^{t} x(\tau)d\tau$	T.I.V.
$y(t) = \mathrm{Even}\{x(t)\}$	T.V.	$y[t] = e^{-2k}.x(t)$	T.I.V.
$y[n] = \mathrm{Odd}\{x(t)\}$	T.V.	$y[n] = \sum_{k=-\infty}^{\lvert n \rvert} x(k)$	T.V.

iii. **Causal and non-causal system-** A system is said to be causal, if the present output depends upon the present input and past values of input but not on the future values. A system is called non-causal if is not causal.

Ex. of causal system $\to y(t) = x(\sqrt{t})$

- All memory-less systems are causal, but not vice-versa

iv. **Static and dynamic systems- A** system is said to be static or memory less if the output at any instant depends only on the input at that instant otherwise, the system is a dynamic system with memory.

Ex. of static system$\to$ $y(t) = 2x(t)$

v. **Stable and unstable systems-** A system is bounded input bounded output i.e. BIBO stable if for any bounded input X the corresponding output Y is also bounded otherwise it is unstable system.

Ex. stable system$\to$ $y(t) = e^{x(t)}$

vi. **Invertible and Non-Invertible system** -If it is possible to define an inverse system of a given system, then the system is invertible, otherwise it is called non-invertible system.

Ex. $y(t) = \int_{-\infty}^{t} x(t)dt$ (Invertible)

$y(t) = \frac{d}{dt}x(t)$ (Inversesystem)

❑ Convolution

• Convolution in continuous time

$$r(t) = f(t) * h(t) = \int_{-\infty}^{\infty} f(\tau)h(t-\tau)d\tau$$

■ Properties

- ➢ $f(t) * \delta(t) = f(t)$
- ➢ $f(t - t_0) * \delta(t) = f(t - t_0)$
- ➢ $f(t) * \delta(t - t_0) = f(t - t_0)$
- ➢ $f(t - t_0) * \delta(t - t_1) = f(t - t_0 - t_1)$
- ➢ If $x_1(t) * x_2(t) = y(t)$ then

$$x_1(at)*x_2(at) = \frac{1}{|a|}y(at), a \neq 0$$

• Convolution in discrete time-

$$r[n] = f[n] * h[n] = \sum_{K=-\infty}^{\infty} f(k)h(n-k)$$

- **Properties**
- ➢ $f[n] * \delta[n] = f[n]$
- ➢ $f[n] * \delta[n] = \delta[n]$
- ➢ $f[n-n_0] * \delta[n-n_1] = f[n-n_0-n_1]$
- ➢ $\delta[n-n_0] * \delta[n-n_1] = \delta[n-n_0-n_1]$
- **Commutative property :** $f(t) * h(t) = h(t) * f(t)$
- **Distributive property :** Parallel combination $f(t) * [h_1(t) + h_2(t)] = f(t) * h_1(t) + f(t) * h_2(t)$
- **Associates property:** Series or cascaded combination $f(t)*[h_1(t) * h_2(t)] = [f(t) * h_1(t)] * h_2(t)$

❑ The Laplace Transform

The Bilateral (Two-sided) Laplace Transform

$$X(s) = \int_{-\infty}^{\infty} x(t)e^{-st} dt$$

Inverse Laplace Transform

$$X(t) = \frac{1}{2\pi j}\int_{c-j\infty}^{c+j\infty} X(s)e^{st} ds$$

Unilateral Laplace Transform

$$X(s) = \int_{0}^{\infty} x(t)e^{-st} dt$$

- **Region of convergence (ROC)**
- ➢ The range variation of σ for which the Laplace transform converges is called region of convergence.

i.e. $\int_{-\infty}^{\infty}\left|f(t)e^{-\sigma t}\right| < \infty$

- **Properties of ROC of Laplace Transform-**
- ➢ ROC contains strip lines parallel to $j\omega$ axis in s-plane.

- ROC does not contain any poles, it is bounded by the poles.
- If f(t) is the finite duration and the absolutely integrable then the ROC is entire s-plane.
- If f(t) s a right sided and if the line $R_e\{s\} = \sigma_0$ is in the ROC then all values of s for which $R_e\{s\} > \sigma_0$ will also be in ROC.

Note :

- For stability ROC must include imaginary axis.
- Solutions of Laplace transform is unique only when the ROC is given.

- **Laplace Transforms Pairs**

x(t)	X(s)	ROC
$\delta(t)$	1	All s
$u(t)$	$\frac{1}{s}$	Re(s)>0
$-u(-t)$	$\frac{1}{s}$	Re(s)<0
$tu(t)$	$\frac{1}{s^2}$	Re(s)>0
$t^k u(t)$	$\frac{k!}{s^{k+1}}$	Re(s)>0
$e^{-at}u(t)$	$\frac{1}{s+a}$	$Re(s) > -Re(a)$
$-e^{-at}u(-t)$	$\frac{1}{s+a}$	$Re(s) < -Re(a)$
$te^{-at}u(t)$	$\frac{1}{(s+a)^2}$	$Re(s) > -Re(a)$
$-te^{-at}u(-t)$	$\frac{1}{(s+a)^2}$	$Re(s) < -Re(a)$
$[\cos\omega_0 t]u(t)$	$\frac{s}{s^2+\omega_0^2}$	Re(s)>0
$[\sin\omega_0 t]u(t)$	$\frac{\omega_0}{s^2+\omega_0^2}$	Re(s)>0
$[e^{-at}\cos\omega_0 t]u(t)$	$\frac{s+a}{(s+a)^2+\omega_0^2}$	$Re(s) > -Re(a)$
$[e^{-at}\sin\omega_0 t]u(t)$	$\frac{\omega_0}{(s+a)^2+\omega_0^2}$	$Re(s) > -Re(a)$

- **Properties of the Laplace Transform**

Property	Signal	Transform	ROC
Linearity	$a_1x_1(t)+a_2x_2(t)$	$a_1X_1(s)+a_2X_2(s)$	$R' \supset R_1 \cap R_2$
Time shifting	$x(t-t_0)$	$e^{-st_0}X(s)$	$R' = R$
Shifting in s	$e^{s_0t}x(t)$	$X(s-s_0)$	$R' = R + Re(s_0)$
Time scaling	$x(at)$	$\frac{1}{\lvert a\rvert}X\left(\frac{s}{a}\right)$	$R' = aR$
Time reversal	$x(-t)$	$X(-s)$	$R' = -R$
Differentiation in t	$\frac{dx(t)}{dt}$	$sX(s)-x(0)$	$R' = R$
Differentiation in s	$tx(t)$	$-\frac{dX(s)}{ds}$	$R'=R$
	$t^n x(t)$	$(-1)^n \frac{d^nX(s)}{ds^n}$	
Integration	$\int_0^t x(\tau)d\tau$	$\frac{1}{s}X(s)$	$R' = R \cap \{Re(s) > 0\}$
Convolution	$x_1(t)*x_2(t)$	$X_1(s)X_2(s)$	$R' \supset R_1 \cap R_2$

- Initial value theorem $x(0) = \lim_{s\to\infty} sX(s)$
- Final value theorem $x(\infty) = \lim_{s\to 0} sX(s)$

Note :

- Initial value theorem is applicable only for proper Laplace i.e. denominator power of function is more than numerator power.
- Final value theorem is not valid when poles lies in right side of s-plane.

❑ Z-Transform- $X(z) = \sum_{n=-\infty}^{\infty} x(n)z^{-n}$

Unilateral Z-Transform $X(z) = \sum_{n=0}^{\infty} x(n)z^{-n}$

Inverse Z-Transform $X(n) = \frac{1}{2\pi j}\oint_c X(z)z^{n-1}dz$

- **Stability**
- An LTI system is stable if and only if the ROC of its system function H(z) includes the unit circles, |Z| =1.

- ➢ A causal LTI system with rational system function H(z) is stable if and only if all of the poles of H(z) lie inside the unit circle i.e., the must all have magnitude smaller than 1.

- **Some Common Z-Transform pairs**

x(n)	X(z)	ROC
$\delta[n]$	1	All z
u[n]	$\frac{1}{1-z^{-1}}$	|z|>1
−u[−n-1]	$\frac{1}{1-z^{-1}}$	|z|<1
$\delta[n-m]$	z^{-m}	All z except 0 if (m>0) or ∞ if (m<0)
$a^n u[n]$	$\frac{1}{1-az^{-1}}$	|z|>|a|
$-a^n u[-n-1]$	$\frac{1}{1-az^{-1}}$	|z|<|a|
$na^n u[n]$	$\frac{az^{-1}}{\left(1-az^{-1}\right)^2}$	|z|>|a|
$-na^n u[-n-1]$	$\frac{az^{-1}}{\left(1-az^{-1}\right)^2}$	|z|<|a|
$[\cos\omega_0 n]u[n]$	$\frac{z^2-(\cos\omega_0)z}{z^2-(2\cos\omega_0)z+1}$	|z|>1
$[\sin\omega_0 n]u[n]$	$\frac{(\sin\omega_0)z}{z^2-(2\cos\omega_0)z+1}$	|z|>1

- **Some properties of the Z- Transform**

Property	Sequence	Transform	ROC
Linearity	$a_1x_1[n]+a_2x_2[n]$	$a_1X_1(z)+a_2X_2(z)$	$R'=R_1\cap R_2$
Time shifting	$x(n-n_0)$	$z^{-n_0}X(z)$	$R'=R$
Multiplication by Z_0^n	$z_0^n\,x[n]$	$X\left(\frac{Z}{Z_0}\right)$	$R'=\lvert Z_0\rvert R$
Multiplication by $e^{j\omega_0 n}$	$e^{j\omega_0 n}x[n]$	$X\left(e^{-j\omega_0}Z\right)$	$R'=R$
Time reversal	x[-n]	$X\left(\frac{1}{Z}\right)$	$R'=\frac{1}{R}$
Multiplication by n	nx [n]	$-z\frac{dX(z)}{dz}$	$R'=R$
Accumulation	$\sum_{k=-\infty}^{n}x[k]$	$\frac{1}{1-z^{-1}}X(z)$	$R'=R\cap\{\lvert z\rvert>1\}$
Convolution	$x_1[n]*x_2[n]$	$X_1(z)X_2(z)$	$R'=R_1\cap R_2$

Initial value theorem $f(0)=\lim_{z\to\infty}F(z)$

Final value theorem $f(\infty)=\lim_{z\to 1}(z-1)F(z)$

(If final value exists)

❑ Fourier Series

- It is an approximation process by which any non-sinusoidal waveform is converted into sinusoidal waveform.
- A Fourier analysis also called as a harmonic analysis.
- **Dirichlet's conditions :** conditions for Fourier series to exist.

1. $\int_T |f(t)|dt<\infty$
2. There must be finite number of maxima and minima in a given time period for f (t).
3. There must be finite number of discontinuities in a given time period for f (t).

- **Condition for orthogonality**
  Signal $x_1(t)$ and $x_2(t)$ are said to be orthogonal if

$$\boxed{\int_{-\infty}^{\infty} x_1(t).x_2(t)=0}$$

i.e. area of $[x_1(t).\,x_2(t)]$ graph = 0

- **Fourier series representation of continuous time periodic signals**

1. **Trigonometric Fourier series**

$$f(t)=a_0+\sum_{n=1}^{\infty}(a_n\cos\omega_0 t+b_n\sin\omega_0 t)$$

Where, ω_0 = Fundamental frequency

a_0 , a_n , b_n = Trigonometric Fourier series coefficient

$n\omega_0$ = n^{th} harmonic of ω_0

$$a_0=\frac{1}{T}\int_0^T f(t)dt\,,\quad a_n=\frac{2}{T}\int_0^T f(t)\cos n\omega_0 t\,dt$$

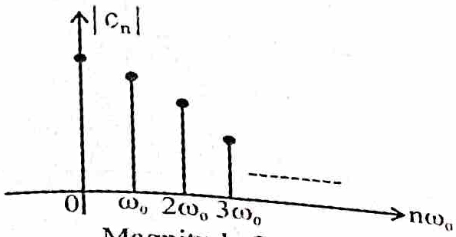
$$b_n=\frac{2}{T}\int_0^T f(t)\sin n\omega_0 t\,dt$$

- Here a_0 is the value of constant component of the signal f(t).
- The Fourier coefficient a_n and b_n are maximum amplitude of n^{th} harmonic component.

2. **Polar form of Trigonometric Fourier series**

$$f(t) = C_0 + \sum_{n=1}^{\infty} C_n \cos(n\omega_0 t - \phi_n)$$

Where, $C_0 = a_0$, $|C_n| = \sqrt{a_n^2 + b_n^2}$, $\phi_n = \tan^{-1}\left(\frac{b_n}{a_n}\right)$



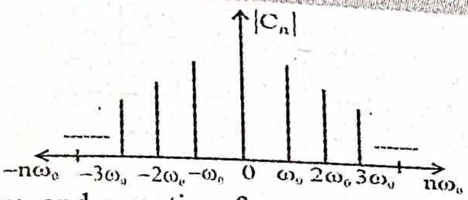
Magnitude Spectrum

3. **Exponential Fourier series-**

$f(t) = \sum_{n=-\infty}^{\infty} C_n e^{jn\omega_0 t}$ Where, $C_0 = a_0 = \frac{1}{T}\int_0^T f(t)dt$

$$\boxed{C_n = \frac{1}{T}\int_0^T f(t)e^{-jn\omega_0 t}dt}$$

Note- Exponential Fourier series is compact form of Fourier series.



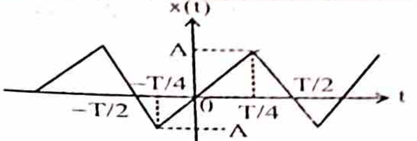
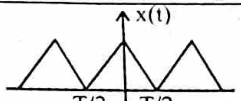
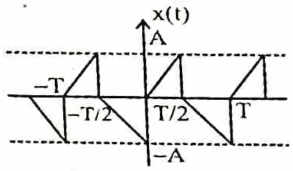
Positive and negative frequency indicate different phase of rotation, they maintain same magnitude but different phase.

- **Relation between exponential and Trigonometric Fourier series–**

$a_n = (C_n + C_{-n})$, $C_n = \frac{a_n}{2} - j\frac{b_n}{2}$

$b_n = j(C_n - C_{-n})$, $C_{-n} = \frac{a_n}{2} + j\frac{b_n}{2}$

- **Effect of symmetry of Fourier coefficients**

Odd Symmetry	 $x(t) = -x(-t)$ For signals with odd symmetry, the Fourier coefficients a_0 and a_n are zero.
Even symmetry-	 $x(t) = x(-t)$ For signals with even symmetry, the Fourier coefficient b_n is zero.
Half-wave symmetry	$\boxed{x(t) = -x\left(t \pm \frac{T_0}{2}\right)}$ For HWS signal, average value will equal to zero, but converse of this statement is not true  $x(t \pm T/2) = -x(t)$ For signals with half-wave symmetry, the Fourier series will consist of odd harmonic terms of sine and cosine signals..

Function	C_n	Fourier Coefficient	Trigonometric Fourier series
Real (Neither even nor odd)	Generally complex $C_n = C^*_{-n}$	$a_0 \neq 0$ $a_n = b_n \neq 0$	DC term, sine terms and cosine terms are present
Even	Real (Even in nature)	$a_0 \neq 0$ $a_n \neq 0$ $b_n = 0$	DC term and cosine terms are present
Odd	Imaginary (odd in nature)	$a_0 = 0$ $a_n = 0$ $b_n \neq 0$	Only sine terms are present
Half wave symmetry	$C_n = 0$; For n = even	$\left.\begin{matrix}a_n = 0\\ b_n = 0\end{matrix}\right\}; a_0 = 0$;n = even	Odd sine and odd cosine terms are present
Even and half wave symmetry	C_n = Real & even $C_n = 0$; n = even	$\left.\begin{matrix}a_n = 0\\ b_n = 0\end{matrix}\right\}; a_0 = 0$ n = even	Only odd cosine terms are present
Odd and half wave symmetry	C_n = imaginary & odd $C_n = 0$; n = even	$\left.\begin{matrix}a_n = 0\\ b_n = 0\end{matrix}\right\}$; n = even	Only odd sine terms are present

- **Properties of Exponential form of Fourier series coefficients**

Property	**Continuous time periodic signal**	**Fourier series coefficients**
Linearity	$Ax(t) + By(t)$	$AC_n + Bd_n$
Time shifting	$x(t \pm t_0)$	$C_n e^{\pm jm\omega_0 t_0}$
Frequency shifting	$e^{\pm jm\omega_0 t}x(t)$	$C_{n\mp m}$
Conjugation	$x^*(t)$	C^*_{-n}
Time reversal	$x(-t)$	C_{-n}
Time scaling	$x(\alpha t); \alpha > 0$ [x(t) is period with period T/α]	C_n (No change in Fourier coefficient)
Multiplication	$x(t)\ y(t)$	$\sum_{m=-\infty}^{+\infty} c_m d_{n-m}$
Differentiation	$\frac{d}{dt}x(t)$	$jn\omega_0 c_n$
Integration	$\int_{-\infty}^{t} x(t)\,dt$ (Finite valued and periodic only if $a_0 = 0$)	$\frac{1}{jn\omega_0}c_n$
Periodic convolution	$\int_T x(\tau)y(t-\tau)d\tau$	$TC_n d_n$
Symmetry of real signals	x(t) is real	$C_n = C^*_{-n}$ $\lvert C_n\rvert = \lvert C_{-n}\rvert$; $\angle C_n = -\angle C_{-n}$ Re $\{C_n\}$ = Re $\{C_{-n}\}$ Im $\{C_n\}$ = –Im $\{C_{-n}\}$
Real and even	x(t) real and even	C_n are real and even
Real and odd	x(t) real and odd	C_n are imaginary and odd
Imaginary and even	x(t) imaginary and even	C_n, imaginary and even
Imaginary and odd	x(t), imaginary and odd	C_n, real and odd

Where, $C_n \rightarrow$ Fourier series coefficient of x(t)

$d_n \rightarrow$ Fourier series coefficients of y(t)

- **Fourier Series Representation of Discrete Time Periodic Signals-**
Fourier series representation of x[n], with period 'N' is given as-

$$x[n] = \sum_{k=0}^{N-1} C_k e^{jk\left(\frac{2\pi}{N}\right)n} \text{,Where,}$$

$$C_k = \frac{1}{N}\sum_{n=0}^{N-1} x[n]e^{-jk\left(\frac{2\pi}{N}\right)n}$$

C_k is periodic with period 'N', $C_k = C_{k+N}$

- **Properties of Discrete Time Fourier Series**

Property	**Continuous time periodic signal**	**Fourier series coefficient**
Linearity	$Ax[n] + By[n]$	$AC_k + Bd_k$
Time shifting	$x[n \pm n_0]$	$C_k e^{\pm jk\left(\frac{2\pi}{N}\right)n_0}$
Frequency shifting	$e^{\pm jM\left(\frac{2\pi}{N}\right)n} x[n]$	$C_{k\mp m}$
Conjugation	$x^*[n]$	C^*_{-k}
Time reversal	$x[-n]$	C_{-k}
Time scaling	$x_{(m)}[n]$ $= \left\{ x\left[\frac{n}{m}\right] \right.$; if n is a multiple of m 0 ; otherwise	$\frac{1}{m}C_k$ (Period mN)
Multiplication	$x[n]\ y[n]$	$\sum_{l=0}^{N-1} C_l b_{k-l}$
First difference	$x[n] - x[n-1]$	$\left(1 - e^{-j\left(\frac{2\pi}{N}\right)k}\right)C_k$
Running sum	$\sum_{k=-\infty}^{n} x[k]$	$\left(\frac{1}{1-e^{-jk\left(\frac{2\pi}{N}\right)}}\right)C_k$
Convolution	$\sum_{r=0}^{N-1} x[r]y[n-r]$	$Na_k d_k$

- **Parseval's Power Theorem-** Parseval's power theorem is given by

⇒ For continuous time signals,

$$P = \frac{1}{T}\int_0^T |x(t)|^2 dt = \sum_{n=-\infty}^{\infty} |C_n|^2 = a_0^2 + \frac{1}{2}\sum_{n=1}^{\infty}(a_n^2 + b_n^2)$$

⇒ For discrete signals,

$$P = \frac{1}{N}\sum_{n=0}^{N-1}|x[n]|^2 = \sum_{k=0}^{N-1}|C_k|^2$$

❑ The Fourier Transform-

$$X(\omega) = \int_{-\infty}^{\infty} x(t)e^{-j\omega t}dt\,, \quad x(t) = \frac{1}{2\pi}\int_{-\infty}^{\infty} X(\omega)e^{j\omega t}d\omega$$

- **Common Fourier Transform pairs**

x(t)	**X(ω)**	**x(t)**	**X(ω)**
$\delta(t)$	1	$e^{-at}u(t), a > 0$	$\frac{1}{j\omega + a}$

$\delta(t-t_0)$	$e^{-j\omega t_0}$	$te^{-at}u(t), a>0$	$\frac{1}{(j\omega+a)^2}$
1	$2\pi\delta(\omega)$	$e^{-a\|t\|}, a>0$	$\frac{2a}{a^2+\omega^2}$
$e^{j\omega_0 t}$	$2\pi\delta(\omega-\omega_0)$	$\frac{1}{a^2+t^2}$	$e^{-a\|\omega\|}$
$u(t)$	$\pi\delta(\omega)+\frac{1}{j\omega}$	sgn(t)	$\frac{2}{j\omega}$
$u(-t)$	$\pi\delta(\omega)-\frac{1}{j\omega}$		
$\cos\omega_0 t$	$\pi[\delta(\omega-\omega_0)+\delta(\omega+\omega_0)]$		
$\sin\omega_0 t$	$-j\pi[\delta(\omega-\omega_0)-\delta(\omega+\omega_0)]$		

- **Properties of the Fourier transform**

Property	Signal	Fourier transform
Linearity	$a_1x_1(t)+a_2x_2($	$a_1X_1(\omega)+a_2X_2(\omega)$
Time shifting	$x(t-t_0)$	$e^{-j\omega t_0}X(\omega)$
Frequency shifting	$e^{j\omega_0 t}x(t)$	$X(\omega-\omega_0)$
Time scaling	$x(at)$	$\frac{1}{\|a\|}X\left(\frac{\omega}{a}\right)$
Time reversal	$x(-t)$	$X(-\omega)$
Duality	$x(t)$	$2\pi X(-\omega)$
Time differentiation	$\frac{dx(t)}{dt}$	$j\omega X(\omega)$
Frequency differentiation	$(-jt)x(t)$	$\frac{dX(\omega)}{d\omega}$
Integration	$\int_{-\infty}^{t}x(\tau)d\tau$	$\pi X(0)\delta(\omega)+\frac{1}{j\omega}X(\omega)$
Convolution	$x_1(t)*x_2(t)$	$X_1(\omega)X_2(\omega)$
Multiplication	$x_1(t)x_2(t)$	$\frac{1}{2\pi}X_1(\omega)*X_2(\omega)$

❑ Discrete time Fourier Transform (DTFT)

$$\text{DTFT}\{x[n]\}=X[\Omega]=\sum_{n=-\infty}^{+\infty}x[n]e^{-j\Omega n}$$

Where 'Ω' is discrete time frequency in 'rad/number'. The transform $X(\Omega)$ is frequency domain description of $x[n]$

Note:

$$\underset{\text{(Discrete aperiodic)}}{x[n]}\xrightarrow{\text{DTFT}}\underset{\text{(Periodic continuous)}}{X[\Omega]}$$

- **Inverse Discrete Time Fourier Transform (IDTFT)**

$$\text{IDTFT}\{X(\Omega)\}=x[n]=\frac{1}{2\pi}\int_{2\pi}X(\Omega)e^{j\Omega n}d\Omega$$

- **Properties of DTFT**

Property	Sequence	Fourier Transform
	$x[n]$	$X(\Omega)$
	$x_1[n]$	$X_1(\Omega)$
	$x_2[n]$	$X_2(\Omega)$
Periodicity	$x[n]$	$X(\Omega+2\pi)=X(\Omega)$
Linearity	$a_1x_1[n]+a_2x_2[n]$	$a_1X_1(\Omega)+a_2X_2(\Omega)$
Time shifting	$x[n-n_0]$	$e^{-j\Omega n_0}X(\Omega)$
Frequency shifting	$e^{j\Omega_0 n}x[n]$	$X(\Omega-\Omega_0)$
Conjugation	$x^*[n]$	$X^*(-\Omega)$
Time reversal	$x[-n]$	$X(-\Omega)$
Time scaling	$x_{(m)}[n]=\begin{cases}x[n/m] & \text{if } n=km\\ 0 & \text{if } n\neq km\end{cases}$	$X(m\Omega)$
Frequency differentiation	$nx[n]$	$j\frac{dX(\Omega)}{d\Omega}$
First difference	$x[n]-x[n-1]$	$(1-e^{-j\Omega})X(\Omega)$
Accumulation	$\sum_{k=-\infty}^{\infty}x[k]$	$\pi X(0)\delta(\Omega)+\frac{1}{1-e^{j\Omega}}X(\Omega), \|\Omega\|\leq\pi$
Convolution	$x_1[n]*x_2[n]$	$X_1(\Omega)X_2(\Omega)$
Multiplication	$x_1[n]x_2[n]$	$\frac{1}{2\pi}X_1(\Omega)\otimes X_2(\Omega)$

Real sequence	$x[n]=x_e[n]+x_0[n]$	$X(\Omega)=A(\Omega)+jB(\Omega), X(-\Omega)=X^*(\Omega)$
Even component	$x_e[n]$	$R_e\{X(\Omega)\}=A(\Omega)$
Odd component	$x_0[n]$	$j\text{Im}\{X(\Omega)\}=jB(\Omega)$
Parseval's relations	$\sum_{n=-\infty}^{\infty}x_1[n]x_2[n]=\frac{1}{2\pi}\int_{2\pi}X_1(\Omega)X_2(-\Omega)d\Omega$ $\sum_{n=-\infty}^{\infty}\lvert x[n]\rvert^2=\frac{1}{2\pi}\int_{2\pi}\lvert X(\Omega)\rvert^2 d\Omega$	

- **Some Common Discrete Time Fourier Transform Pair**

Sequence	Fourier Transform
$x[n]$	$X(\Omega)$
$\delta[n]$	1
$\delta[n-n_0]$	$e^{-j\Omega n_0}$
$x[n]=1$	$2\pi\delta(\Omega),\lvert(\Omega)\rvert\le\pi$
$e^{j\Omega_0 n}$	$2\pi\delta(\Omega-\Omega_0),\lvert\Omega_0\rvert\le\pi$
$\cos\Omega_0 n$	$\pi[\delta(\Omega-\Omega_0)+\delta(\Omega+\Omega_0),\lvert\Omega\rvert,\lvert\Omega_0\rvert]\le\pi$
$\sin\Omega_0 n$	$-j\pi[\delta(\Omega-\Omega_0)-\delta(\Omega+\Omega_0),\lvert\Omega\rvert,\lvert\Omega_0\rvert]\le\pi$
$u[n]$	$\pi\delta(\Omega)+\frac{1}{1-e^{-j\Omega}},\lvert\Omega\rvert\le\pi$
$-u[-n-1]$	$-\pi\delta(\Omega)+\frac{1}{1-e^{-j\Omega}},\lvert\Omega\rvert\le\pi$
$a^n u[n],\lvert a\rvert<1$	$\frac{1}{1-ae^{-j\Omega}}$
$-a^n u[-n-1],\lvert a\rvert>1$	$\frac{1}{1-ae^{-j\Omega}}$
$(n+1)a^n u[n],\lvert a\rvert<1$	$\frac{1}{(1-ae^{-j\Omega})^2}$
$a^{\lvert n\rvert},\lvert a\rvert<1$	$\frac{1-a^2}{1-2a\cos\Omega+a^2}$
$x[n]=\begin{cases}1 & \lvert n\rvert\le N_1\\ 0 & \lvert n\rvert>N_1\end{cases}$	$\frac{\sin\left[\Omega\left(N_1+\frac{1}{2}\right)\right]}{\sin(\Omega/2)}$
$\frac{\sin Wn}{\pi n},0<W<\pi$	$X(\Omega)=\begin{cases}1 & 0\le\lvert\Omega\rvert\le W\\ 0 & W<\lvert\Omega\rvert\le\pi\end{cases}$
$\sum_{k=-\infty}^{\infty}\delta[n-kN_0]$	$\Omega_0\sum_{k=-\infty}^{\infty}\delta(\Omega-k\Omega_0),\Omega_0=\frac{2\pi}{N_0}$

- **Discrete Fourier Transform (DFT)**

➢ The Discrete Fourier transform (DFT) is basically fourier transform of "sampled signal repeated periodically". The number of point in DFT known as N-point DFT.

$$\text{DFT}\{x[n]\}=X[K]=\sum_{n=0}^{N-1}x[n]e^{-j\frac{2\pi K}{N}n}$$

Note: $\underset{\text{Discrete periodic}}{x[n]}\xleftrightarrow{\text{DFT}}\underset{\text{Discrete periodic}}{X[K]}$

- **Inverse DFT**

$$x[n]=\frac{1}{N}\sum_{K=0}^{N-1}X[K]e^{j\frac{2\pi K}{N}n}$$

Where 'N' is period of the signal x[n]

- **Properties of DFT**
- **Linearity**

Then $x_1[n]\xleftrightarrow{\text{DFT}}X_1[K]$

$x_2[n]\xleftrightarrow{\text{DFT}}X_2[K]$

Then $\alpha x_1[n]+\beta x_2[n]\xleftrightarrow{\text{DFT}}\alpha X_1[K]+\beta X_2[K]$

- **Time shifting**

If $x[n]\xleftrightarrow{\text{DFT}}X[K]$

Then $x[n-n_0]\xleftrightarrow{\text{DFT}}e^{-j\frac{2\pi}{N}Kn_0}X[K]$

- **Shift in k-domain**

If $x[n]\xleftrightarrow{\text{DFT}}X[K]$

Then x[n]

$e^{j\frac{2\pi}{N}K_0 n}\xleftrightarrow{\text{DFT}}X[K-K_0]$

- **Conjugate symmetry**

If $x[n]\xleftrightarrow{\text{DFT}}X[K]$

Then $x^*[n]\xleftrightarrow{\text{DFT}}X^*[-K]$

- **Time reversal**

If $x[n]\xleftrightarrow{\text{DFT}}X[K]$

Then $x[-n]\xleftrightarrow{\text{DFT}}X[-K]$

Or $x[N-n]\xleftrightarrow{\text{DFT}}X[N-K]$

- **Periodic convolution**

If $x_1[n]\xleftrightarrow{\text{DFT}}X_1[K]$ (with period N₀)

And $x_2[n]\xleftrightarrow{\text{DFT}}X_2[K]$ (with period N₀)

Then $x_1[n]\,Ⓝ\,x_2[n]\xleftrightarrow{\text{DFT}}X_1[K]X_2[K]$

(with period N₀)

- **Linear Convolution**

If $x_1[n]\xleftrightarrow{\text{DFT}}X_1[K]$ (with period N₁)

And $x_2[n]\xleftrightarrow{\text{DFT}}X_2[K]$ (with period N₂)

Then $x_1[n]*x_2[n]\xleftrightarrow{\text{DFT}}X_1[K]X_2[K]$

(with period N_1+N_2-1)

- **Parseval's relation**

$$E=\sum_{n=0}^{N-1}|x[n]|^2=\frac{1}{N}\sum_{k=0}^{N-1}|x[K]|^2$$

- **Correlation-** The correlation of two functions or signals or waveforms is defined as the measure of similarity between those signals. There are two types of correlations-

(i) Cross-correlation (ii) Auto-correlation

- For two signals $f(t)$ and g(t), correlation is defined as-

$$R_{fg}(\tau)=\int_{-\infty}^{\infty}f(t)g(t-\tau)dt=\left[f(t)\otimes g(-t)\right]_{t=\tau}$$

- Auto correlation function is a special case where both the signals are same.

For energy signals,

$$R_{ff}(\tau)=\int_{-\infty}^{\infty}f(t)f(t-\tau)dt=\left[f(t)\otimes f(-t)\right]_{t=\tau}$$

For power signals,

$$R_{ff}(\tau)=\lim_{s\to\infty}\frac{1}{T}\int_{-\infty}^{\infty}f(t)f(t-\tau)d\tau$$

- **Properties of auto-correlation function**
- $R_{ff}(\tau)$ is even, $R_{ff}(\tau)=R_{ff}(-\tau)$
- $R_{ff}(0)>R_{ff}(\tau)$
- For energy signals, energy = $R_{ff}(0)$

  For power signals, power = $R_{ff}(0)$
- For energy signals, Fourier transform of $R_{ff}(\tau)$ gives energy spectral density, i.e.

  $R_{ff}(\tau)\to F(\omega)F^*(\omega)[ESD_f]$

  For power signals, Fourier transform of $R_{ff}(\tau)$ gives power spectral density, i.e.

  $$R_{ff}(\tau)\longleftrightarrow\lim_{T\to\infty}\frac{|F_T(\omega)|^2}{T}[PSD_f]$$

- **Fast Fourier Transform**

The Fast Fourier Transform is an algorithm that computes the discrete Fourier Transform (DFT) of a sequence. It reduces the number of the computations needed to find transform.

For N- Point DFT

Number of multiplications = $\frac{N}{2}\log_2 N$

Number of additions = N $\log_2$N

- **Sampling**

Any band limited signal x(t) is uniquely determined by its samples if the sampling frequency (ω_s) is greater than twice the maximum frequency (ω_m) present in the signal.

There are two types of sampling.

- Ideal/instantaneous sampling (zero pulse width)
- Practical sampling (Non-zero pulse width)

(i) Natural sampling (ii) Flat top sampling

❑ Digital filters:

Digital filter is a system that performs mathematical operations on a sampled, discrete time signal to reduce or enhance parameters of that signal. There are two types-

- **Finite Impulse Response (FIR) filter-** The impulse response is of finite duration. The differences equation is given by-

$$y[n]=\sum_{i=0}^{N}b_i x[n-i]$$

Where, $x[n], y[n]\to$ Input and output respectively

N→ Filter order

b_i→ Value of impulse response at i^{th} instant

- **Properties-**
  - ➢ No feedback is required
  - ➢ They are inherently stable.
  - ➢ They can be easily designed to be linear phase by making the coefficient sequence symmetric.
  - ➢ Computationally complex.
- **Basic Structure for FIR systems**
  - ➢ The system function of the FIR system whose realization take the form of a non-recursive computational algorithm may be written as-

$$H(z)=\sum_{n=0}^{M-1}h(n)z^{-n}$$

That is if the impulse response is M samples in duration, the H(z) is a polynomial in Z^{-1} of degree M–1. Thus H(z) has (M-1) poles at Z = 0 and (M-1) zeros that can be anywhere in the finite z-plane.

- **Infinite impulse response filters.**
  - ➢ The impulse response of IIR filters continues indefinitely. The difference equation is given as-

$$y[n]=\frac{1}{a_0}\left(\sum_{i=0}^{P}b_i x[n-i]-\sum_{j=1}^{Q}a_j y[n-j]\right)$$

Where,

P→ Feed forward filter orders

Q→ feedback filter order

b_i→ Feedforward filter coefficients

a_j→ Feedback filter

- **Properties**
  - ➢ Feedback is required
  - ➢ Stability depends on the filter coefficients
  - ➢ They are preferred over FIR filters for their efficiency in implementation.
- **Basic structures for IIR systems.**
  - ➢ Causal IIR systems are characterized by the constant coefficient difference equation or equivalently, by the real rational transfer function of equation. From these equations, it can be seen that the realization of infinite duration impulse response (IIR) systems involves a recursive computational algorithm. In this section, the most important filter structures namely direct forms- I and II, cascade and parallel realizations for IIR system are discussed.

$$H(z)=\frac{y(z)}{x(z)}=\frac{\sum_{k=0}^{M}b_k z^{-k}}{\sum_{k=1}^{N}a_k z^{-k}}$$

ENGINEERING MATHEMATICS

Linear Algebra

Basic Operation

$\lvert A^T \rvert = \lvert A \rvert$	$\lvert AB \rvert = \lvert A \rvert \lvert B \rvert$
$\lvert A+B \rvert \neq \lvert A \rvert + \lvert B \rvert$	$\lvert KA \rvert = K^n \lvert A \rvert$, A = square matrix
$A = \begin{vmatrix} a_{11} & a_{12} \\ b_{21} & b_{22} \end{vmatrix}_{2\times 2}$	If $a_{11} = a_{12} = 0$ or $b_{21} = b_{22} = 0$ $\lvert A \rvert = 0$

☞ Remember point

- Area of a triangle whose vertices are (x_1,y_1), (x_2,y_2) and (x_3,y_3) is

$$\text{Area of triangle} = \frac{1}{2}\begin{vmatrix} x_1 & y_1 & 1 \\ x_2 & y_2 & 1 \\ x_3 & y_3 & 1 \end{vmatrix}$$

- Area of a quadrilateral can be found by dividing it into two triangles.
- The condition for three points to be collinear is

$$\frac{1}{2}\begin{vmatrix} x_1 & y_1 & 1 \\ x_2 & y_2 & 1 \\ x_3 & y_3 & 1 \end{vmatrix} = 0$$

Eigen value	Eigen vector
Sum of Eigen value $\left[\sum_i (\lambda_i)\right]$ = Trace of matrix	$[A-\lambda I][X] = 0$ $AX = \lambda X$
Product of Eigen value $\left[\prod_i (\lambda_i)\right]$ = Determinant of matrix	Eigen vector of matrix A, A^2, A^{-1}, adj A are always same
Hermitian matrix = Real Symmetric matrix → Always real Skew Symmetric matrix →Either zero or purely imaginary Unitary matrix has absolute value	Eigen vector corresponding to the distinct eigen value of a real symmetric matrix are always orthogonal.

☞ Remember point

$\lvert A - \lambda I \rvert = 0$ is characteristic equation

Cayley-Hamilton Theorem-

Every square matrix satisfy its characteristics equation. $p(x) = \det(A - \lambda I)$

or $a_0 A^n + a_1 A^{n-1} + \ldots\ldots\ldots a_n I = 0$

Types of square matrix

Type of square matrix	Details	Property
Diagonal matrix	$[a_{ij}]_{i=j} \neq 0$	
Scalar matrix	$[a_{ij}]_{i=j} = \begin{Bmatrix} 0 & i \neq j \\ k & i = j \end{Bmatrix}$ $= k(\text{constant})$	
Unit matrix or Identity matrix	$[a_{ij}]_{i \neq j} = 0$ $[a_{ij}]_{i=j} = 1$	
Upper triangular matrix	$[a_{ij}] = 0, \; i > j$	$\lvert A \rvert$= product of leading diagonal elements
Lower triangular matrix	$[a_{ij}] = 0, i < j$	
Symmetric matrix	$[A]^T = [A]$	$\frac{A + A^T}{2}$ is always symmetric matrix
Skew symmetric matrix	$[A]^T = -[A]$	$\frac{A - A^T}{2}$ is always skew symmetric matrix
Orthogonal matrix	$A.A^T = I$	$\lvert A \rvert = \pm 1$ $\lvert A \rvert \lvert A^T \rvert = 1$ A^{-1} and A^T also orthogonal
Hermitian matrix	$A = A^\theta$ $\left(A^\theta = (\bar{A})^T\right)$	Diagonal element = real

Skew Hermitian matrix	$A=-A^0$	Diagonal element = zero or purely imaginary
Unitary matrix	$A.A^0=I$	
Idempotent matrix	$A^2=A$	$\lvert A\rvert=0$ or 1
Nilpotent matrix	$A^K=0$	$\lvert A\rvert$ and Trace = 0

☞ **Remember point**

- **Inverse of square matrix** : For a non singular matrix A

$$A^{-1}=\frac{1}{|A|}\text{adj}(A)$$

$$AA^{-1}=A^{-1}A=I$$

■ Rank of matrix

$\rho(A)\le\min(\text{Row},\text{column})$	$\rho(A+B)\le\rho(A)+\rho(B)$
$\rho(AB)\le\min[\rho(A),\rho(B)]$	$\rho(A^\theta)=\rho(A)$
$\rho(A^TA)=\rho(AA^T)$ $=\rho(A)=\rho(A^T)$	$\rho(AA^\theta)=\rho(A)$

☞ **Remember point**

- If A is zero matrix, the $\rho(A)=0$
- If A is not a zero matrix $\rho(A)\ge1$
- If A is non singular $n\times n$ matrix then $\rho(A)=n \qquad (\because|A|\ne0)$

■ Solution of linear simultaneous equation

[A:B]	$\rho(A)\ne\rho(A:B)$	$\rho(A)=\rho(A:B)$
Augmented matrix	Inconsistent =No solution	consistent 1. $\rho(A)=\rho(A:B)$ = number of variable (unique solution) 2. $\rho(A)=\rho(A:B)$ <number of variable (infinite solution)

☞ **Remember point**

If $a_1x+b_1y+c_1=0$

$a_2x+b_2y+c_2=0$

then

(i) $\frac{a_1}{a_2}=\frac{b_1}{b_2}=\frac{c_1}{c_2}\Rightarrow$ Infinity many Solution

(ii) $\frac{a_1}{a_2}\ne\frac{b_1}{b_2}=\frac{c_1}{c_2}\Rightarrow$ Unique Solution

(iii) $\frac{a_1}{a_2}=\frac{b_1}{b_2}\ne\frac{c_1}{c_2}\Rightarrow$ No Solution

(iv) $\frac{a_1}{a_2}\ne\frac{b_1}{b_2}\ne\frac{c_1}{c_2}\Rightarrow$ None

■ Calculus

Concept of continuity	**Concept of differentiability**
$\lim\limits_{x\to a}f(x)=\lim\limits_{x\to a^+}f(x)$ $.\lim\limits_{h\to0}f(a-h)=\lim\limits_{h\to0}f(a+h)$	$\lim\limits_{h\to0}\frac{f(a+h)-f(a)}{h}$ $=\lim\limits_{h\to0}\frac{f(a-h)-f(a)}{-h}=f(a)$

■ Standard Result of limits

$\lim\limits_{x\to0}\frac{\sin x}{x}=1$	$\lim\limits_{x\to\infty}\left(\frac{1}{x}\right)=0$
$\lim\limits_{x\to0}\frac{\tan x}{x}=1$	$\lim\limits_{x\to0}(1+x)^{1/x}=\lim\limits_{x\to\infty}\left(1+\frac{1}{x}\right)^x=e$
$\lim\limits_{x\to0}\cos x=1$	$\lim\limits_{x\to0}\frac{\log(1+x)}{x}=1$
$\lim\limits_{x\to a}\frac{x^n-a^n}{x-a}=na^{n-1}$	$\lim\limits_{x\to0}\frac{a^x-1}{x}=\ell n(a)$
$\lim\limits_{x\to\infty}\frac{\sin x}{x}=\lim\limits_{x\to\infty}\frac{\cos x}{x}=0$	$\lim\limits_{x\to\infty}\left(1+\frac{a}{x}\right)^x=e^a$

• Conditions for L- hospital's rule

$$\frac{0}{0},\frac{\infty}{\infty},\infty\times\infty,0^0,1^\infty,\infty^0,\infty-\infty,\frac{0}{\infty},\frac{\infty}{0},\infty^\infty,0\times\infty,0^\infty$$

If $\lim\limits_{x\to a}\frac{f(x)}{g(x)}\to$ indeterminants form then $\lim\limits_{x\to a}\frac{f'(x)}{g'(x)}$

■ Properties of differentiation

$$\frac{d}{dx}kf(x)=k\frac{d}{dx}f(x)$$

$$\frac{d}{dx}[f(x)\pm g(x)]=\frac{d}{dx}f(x)\pm\frac{d}{dx}g(x)$$

$$\frac{d}{dx}f(x).g(x)=g(x).\frac{d}{dx}f(x)+f(x)\frac{d}{dx}g(x)$$

$$\frac{d}{dx}\left[\frac{f(x)}{g(x)}\right]=\frac{g(x)\frac{d}{dx}f(x)-f(x)\frac{d}{dx}g(x)}{g(x)^2}$$

If h(x) is composite function as h(x) = g[f(x)]

$$\frac{d}{dx}h(x)=\frac{d}{dx}g[f(x)].\frac{d}{dx}f(x)$$

Standard formula of differentiation

Function	Derivative	Function	Derivative
k(constant)	0	$\sin^{-1}\frac{x}{a}$	$\frac{1}{\sqrt{a^2-x^2}}$
x^n	nx^{n-1}	$\cos^{-1}\frac{x}{a}$	$\frac{-1}{\sqrt{a^2-x^2}}$
logx	1/x	$\tan^{-1}\frac{x}{a}$	$\frac{a}{x^2+a^2}$
e^x	e^x	$\cot^{-1}\frac{x}{a}$	$\frac{-a}{x^2+a^2}$
a^x	$a^x\log_e a$	$\sec^{-1}\frac{x}{a}$	$\frac{a}{\lvert x\rvert\sqrt{x^2-a^2}}$
sinx	cosx	$\text{cosec}^{-1}\frac{x}{a}$	$\frac{-a}{\lvert x\rvert\sqrt{x^2-a^2}}$
cosx	–sinx	sinh x	cos h x
tanx	$\sec^2 x$	cosh x	sin h x
cotx	$-\text{cosec}^2 x$	$\sinh^{-1} x$	$\frac{1}{\sqrt{x^2+1}}$
sec x	sec x tan x	$\cosh^{-1} x$	$\frac{1}{\sqrt{x^2-1}}$
cosec x	–cosecx cotx	$\tanh^{-1} x$	$\frac{1}{1-x^2}$

Mean value theorem:

Rolle's theorem	Lagrange's theorem
$f(a)=f(b)$ $f'(c)=0 \qquad c\in(a,b)$	$f(a)\neq f(b)$ $f'(c)=\dfrac{f(b)-f(a)}{b-a}$

Definite Integration

- $\int_a^b f(x)dx = f(b)-f(a)$
- $\int_a^b f(x)dx = \int_a^b f(t)dt$
- $\int_a^b f(x)dx = -\int_b^a f(x)dx$
- $\int_a^b f(x)dx = \int_a^c f(x)dx + \int_c^b f(x)dx \quad \boxed{a<c<b}$
- $\int_0^a f(x)dx = \int_0^a f(a-x)dx$
- $\int_{-a}^a f(x)dx = \begin{Bmatrix} 2\int_0^a f(x)dx & \text{even } f^n \\ 0 & \text{odd } f^n \end{Bmatrix}$
- $\int_0^{2a} f(x)dx = \begin{Bmatrix} 2\int_0^a f(x)dx & \text{if } f(2a-x)=f(x) \\ 0 & \text{if } f(2a-x)=-f(x) \end{Bmatrix}$

Application of definite integral

Application		Formula
Area of Quadrature	Cartesian form	$\int_{x_1}^{x_2}\int_{y_1}^{y_2} dy\,dx$
	polar form	$\int_\alpha^\beta \frac{r^2}{2}d\theta$ or $\iint_s r\,dr\,d\theta$
length of curve	cartesian form	$\int_a^b \sqrt{\left[1+\left(\frac{dy}{dx}\right)^2\right]}dx$
	polar form	$\int_\alpha^\beta \sqrt{\left[r^2+\left(\frac{dr}{d\theta}\right)^2\right]}d\theta$
volume of revolution	x–axis	$\int_a^b \pi y^2 dx$
	y–axis	$\int_a^b \pi x^2 dy$
	$\theta=0$ $\theta=\pi/2$	$\int_\alpha^\beta \frac{2\pi}{3}r^3\sin\theta\,d\theta$ $\int_\alpha^\beta \frac{2\pi}{3}r^3\cos\theta\,d\theta$
volume as double and triple integral	triple integral	$\iiint_v f(x,y,z)dx\,dy\,dz$
	double integral	$\iint_s f(x,y)dx\,dy$

Standard formula of integration

$\int x^n dx = \frac{x^{n+1}}{n+1}+c,(n\neq -1)$	$\int \frac{1}{\sqrt{a^2-x^2}} = \sin^{-1}\frac{x}{a}+c$
$\int \frac{1}{x}dx = \ln\lvert x\rvert + c$	$\int \frac{dx}{a^2-x^2} = \frac{1}{2a}\log\left\lvert\frac{a+x}{a-x}\right\rvert + c$
$\int e^x dx = e^x + c$	$\int \frac{dx}{a^2+x^2} = \frac{1}{a}\tan^{-1}\frac{x}{a}+c$
$\int a^x dx = \frac{a^x}{\log_e a}+c$	$\int \frac{dx}{a^2+x^2} = \frac{-1}{a}\cot^{-1}\frac{x}{a}+c$
$\int \cos x dx = \sin x + c$	$\int \frac{dx}{x\sqrt{x^2-a^2}} = \frac{1}{a}\sec^{-1}\frac{x}{a}+c$
$\int \text{cosec}(x)\cot(x)dx$ $= -\text{cosec}(x)+c$	$\int \frac{dx}{x\sqrt{x^2-a^2}} = \frac{-1}{a}\text{cosec}^{-1}\frac{x}{a}+c$
$\int \sin x dx = -\cos x + c$	$\int \sinh x dx = \cosh x + c$
$\int \sec x \tan x dx = \sec x + c$	$\int \cosh x dx = \sin hx + c$
$\int \sec^2 x dx = \tan x + c$	$\int \frac{dx}{\sqrt{x^2+a^2}} =$ $\log\left[x+\left(\sqrt{x^2+a^2}\right)\right]+c$
$\int \text{cosec}^2 x dx = -\cot x + c$	$\int \frac{dx}{\sqrt{x^2-a^2}} =$ $\log\lvert x+\left(\sqrt{x^2-a^2}\right)\rvert+c$
$\int \cot x dx = \log\sin x + c$	$\int \frac{dx}{x^2-a^2} =$ $\frac{1}{2a}\log\left\lvert\frac{x-a}{x+a}\right\rvert+c$

$\int \tan x dx = \log \sec x + c$	$\int \tan x dx =$ $-\log(\cos x) + c$
$\int \sec x dx = \log(\sec x + \tan x) + c$	$\int \sec x dx =$ $\log \tan\left(\frac{\pi}{4} + \frac{x}{2}\right) + c$
$\int \operatorname{cosec} x dx =$ $\log(\operatorname{cosec} x - \cot x) + c$	$\int \operatorname{cosec} x dx =$ $\log\left(\tan\frac{x}{2}\right) + c$
$\int \sqrt{a^2 - x^2} dx =$ $\frac{1}{2} x\sqrt{a^2 - x^2} + \frac{1}{2} a^2 \sin h^{-1}\left(\frac{x}{a}\right) + c$	$\int \sqrt{a^2 + x^2} dx =$ $\frac{1}{2} x\sqrt{a^2 + x^2}$ $+ \frac{1}{2} a^2 \sin h^{-1}\left(\frac{x}{a}\right) + c$

☞ **Remember point**

Integration of $\int \sin^m x \cos^n x dx$ m, n is positive integers.

i. $m \to$ odd & $n \to$ even, for integration put $t = \cos x$

ii. $m \to$ even & $n \to$ odd, for integration put $t = \sin x$

iii. m & $n \to$ odd, for integration put $t = \cos x$ or $\sin x$

iv. m & $n \to$ even for integration put $t = \cos x$ or $\sin x$

Series expansion :

- **Taylor's series -**

$$f(x) = f(a) + (x-a)f'(a) + \frac{(x-a)^2}{2!} f''(a) + \frac{(x-a)^3}{3!} f'''(a) + ...\infty$$

When $a = 0$ this series become Maclaurin series.

- **Maclaurin's series -**

$$f(x) = f(0) + xf'(0) + \frac{x^2}{2!} f''(0) + \frac{x^3}{3!} f'''(0) + ...\infty$$

➤ $e^x = 1 + \frac{x}{1!} + \frac{x^2}{2!} + \frac{x^3}{3!} + ...\infty$

➤ $e^{-x} = 1 - \frac{x}{1!} + \frac{x^2}{2!} - \frac{x^3}{3!} + ...\infty$

➤ $\frac{e^x + e^{-x}}{2} = \cosh(x) = 1 + \frac{x^2}{2!} + \frac{x^4}{4!} + \frac{x^6}{6!} ....\infty$

➤ $\frac{e^x - e^{-x}}{2} = \sinh(x) = x + \frac{x^3}{3!} + \frac{x^5}{5!} + \frac{x^7}{7!} ....\infty$

➤ $\log(1+x) = x - \frac{x^2}{2} + \frac{x^3}{3} - \frac{x^4}{4} ....\infty \qquad |x| < 1$

➤ $\log(1-x) = -\left[x + \frac{x^2}{2} + \frac{x^3}{3} + \frac{x^4}{4} ....\infty\right] \qquad |x| < 1$

➤ $(1+x)^n = 1 + nx + \frac{n(n-1)}{2!} x^2 + ...\infty$

➤ $\sin x = x - \frac{x^3}{3!} + \frac{x^5}{5!} - \frac{x^7}{7!} + ...\infty$

➤ $\cos x = 1 - \frac{x^2}{2!} + \frac{x^4}{4!} - \frac{x^6}{6!} + ...\infty$

➤ $\tan x = x + \frac{1}{3} x^3 + \frac{2}{15} x^5 + \frac{17}{315} x^7 + ...\infty \qquad |x| < \pi/2$

Gamma function

$$\Gamma(n) = \int_0^\infty e^{-t} t^{n-1} dt \ (n > 0)$$

- $\Gamma\left(\frac{1}{2}\right) = \sqrt{\pi}$
- $\Gamma(n) = (n-1)!$
- $\Gamma(n+1) = \begin{cases} n\Gamma(n) & n \to \text{fraction} \\ n! & n \to \text{integer} \end{cases}$

Beta function

$$\beta(m,n) = \int_0^1 x^{m-1}(1-x)^{n-1} dx \quad (m > 0, n > 0)$$

- $\beta(m,n) = \frac{\Gamma(m)\Gamma(n)}{\Gamma(m+n)}$
- $\int_0^{\pi/2} \sin^m x . \cos^n x dx = \frac{\Gamma\left(\frac{m+1}{2}\right)\Gamma\left(\frac{n+1}{2}\right)}{2\Gamma\left(\frac{m+n+2}{2}\right)}$

Maxima and Minima

- **One independent variable**

$\frac{dy}{dx} = 0$, $\qquad \frac{d^2y}{dx^2} > 0$(minima)

$\frac{d^2y}{dx^2} < 0$(maxima)

- **Two independent variable**

$\frac{\partial f}{\partial x} = 0, \frac{\partial f}{\partial y} = 0, \quad r = \frac{\partial^2 f}{\partial x^2}, s = \frac{\partial^2 f}{\partial x \partial y}, t = \frac{\partial^2 f}{\partial y^2}$

If $\quad rt - s^2 > 0 \quad r > 0 \to$ minima

If $\quad rt - s^2 > 0 \quad r < 0 \to$ maxima

If, $\quad rt - s^2 = \quad 0 \to$ further investigation.

If $\quad rt - s^2 < 0 \to$ neither maxima nor minima

Differential equation

Differential equation	**solution**
Separation of variables. $f(y) dy = \phi(x) dx$	$\int f(y) dy = \int \phi(x) dx + c$
linear first order equation, $\frac{dy}{dx} + P(x)y = Q(x)$	I.F. $= e^{\int P dx}$ $y(\text{I.F.}) = \int Q(\text{I.F.}) dx + c$
Exact Method: M(x,y)dx+N(x,y)dy=0,	$\int Mdx +$ $\int$(term of N not

$\frac{\partial M}{\partial Y}=\frac{\partial N}{\partial x}$	containing x)dy = c
Homogeneous equation $\frac{dy}{dx}=\phi\left(\frac{y}{x}\right)$	$y = vx$ $\frac{dy}{dx}=v+x\frac{dv}{dx}$
Partial Differential equation $a\frac{\partial^2 u}{\partial x^2}+b\frac{\partial^2 u}{\partial x\partial y}+c\frac{\partial^2 u}{\partial y^2}+d\frac{\partial u}{\partial x}+e\frac{\partial u}{\partial y}=F(u)$	
$b^2-4ac>0$	Hyperbolic
$b^2-4ac=0$	Parabolic
$b^2-4ac<0$	Elliptic

One dimensional wave equation	$c^2\frac{\partial^2 u}{\partial x^2}=\frac{\partial^2 u}{\partial t^2}$
One dimensional heat flow	$\frac{\partial u}{\partial t}=c^2\frac{\partial^2 u}{\partial x^2}$
Laplace equation	$\frac{\partial^2 u}{\partial x^2}+\frac{\partial^2 u}{\partial y^2}=0$

- **Euler's Theorem-** If u is a homogenous function of degree n in x and y then

$$x\frac{\partial u}{\partial x}+y\frac{\partial u}{\partial y}=nu \quad \text{Where, } u=x^n f\left(\frac{y}{x}\right)$$

Complementary function

$$\frac{d^n y}{dx^n}+K_1\frac{d^{n-1}y}{dx^{n-1}}+.......+K_n y=0$$

1. $(D-m_1)(D-m_2)=0$

$m_1 \neq m_2, \quad CF=c_1e^{m_1x}+c_2e^{m_2x}$

2. $m_1=m_2 \quad CF=(C_1+C_2x)e^{mx}$

3. $m=a\pm ib \quad CF=e^{ax}(c_1\cos bx+c_2\sin bx)$

4. $m=a\pm ib, a\pm ib \quad CF=e^{ax}$ [$(c_1+c_2x)\cos bx+(c_3+c_4 x)\sin bx$

Particular integral

$$\frac{d^n y}{dx^n}+K_1\frac{d^{n-1}y}{dx^{n-1}}+.......+K_n y=f(x)$$

1. When $f(x)=e^{ax}$ If $f(a)=0$

$$PI=\frac{1}{f(D)}e^{ax}=\frac{1}{f(a)}e^{ax}\Rightarrow x\frac{1}{f'(a)}e^{ax}$$

2. When $f(x)=\sin(ax+b)$ or $\cos(ax+b)$

$$PI=\frac{1}{f(D^2)}\sin(ax+b)=\frac{1}{f(-a^2)}\sin(ax+b)$$

3. $f(x)=x^m$

$$PI=\frac{1}{f(D)}x^m=\{F(D)\}^{-1}x^m$$

4. when $f(x)=e^{ax}\cos bx$ or $e^{ax}\sin bx$ or $e^{ax}x^k$

$PI=\frac{1}{f(D)}e^{ax}v=e^{ax}\left\{\frac{1}{f(D+a)}v\right\}$ Where $v=\cos bx$ or $\sin bx$ or x^k

- **Vector calculus**

Application	**Formula**
Gradient	$\text{grad}(\phi)=\nabla\phi=\left(\hat{i}\frac{\partial}{\partial x}+\hat{j}\frac{\partial}{\partial y}+\hat{k}\frac{\partial}{\partial z}\right)\phi$
Divergence	$\text{div}(\vec{F})=\nabla\cdot\vec{F}=\left(\hat{i}\frac{\partial}{\partial x}+\hat{j}\frac{\partial}{\partial y}+\hat{k}\frac{\partial}{\partial z}\right)\cdot\left(\hat{i}F_1+\hat{j}F_2+\hat{k}F_3\right)$
Curl	$\text{curl}(\vec{F})=\nabla\times\vec{F}=\begin{vmatrix}\hat{i} & \hat{j} & \hat{k}\\ \frac{\partial}{\partial x} & \frac{\partial}{\partial y} & \frac{\partial}{\partial z}\\ F_1 & F_2 & F_3\end{vmatrix}$

- **Fundamental theorem's of vector**

Green's Theorem	**Stoke's Theorem**	**Gauss Theorem**
$\oint_c(\phi dx+\psi dy)=\iint_R\left(\frac{\partial\psi}{\partial x}-\frac{\partial\phi}{\partial y}\right)dx\,dy$	$\oint_c\vec{F}\cdot\vec{dr}=\iint_s \text{curl}\vec{F}\cdot\hat{n}ds$	$\oiint_s\vec{F}\cdot nds=\iiint_v \text{div}.\vec{F}dv$

- **Complex Variable's**

Cauchy Riemann equation $\frac{\partial u}{\partial x}=\frac{\partial v}{\partial y},\frac{\partial u}{\partial y}=-\frac{\partial y}{\partial x}$	In polar form $\frac{\partial u}{\partial r}=\frac{1}{r}\frac{\partial v}{\partial\theta}$ and $\frac{\partial u}{\partial\theta}=-r\frac{\partial v}{\partial r}$

- **Cauchy's integral formula**

For simple pole $\oint_c\frac{f(z)}{z-a}dz=2\pi i f(a)$	Residue- $\text{Res } f(a)=\lim_{z\to a}(z-a)f(z)$
For multiple pole $\oint_c\frac{f(z)}{(z-a)^n}dz$ $=\frac{2\pi i}{(n-1)!}\left(\frac{d^{n-1}}{dz^{n-1}}(z-a)^n f(z)\right)_{z=a}$	$\text{Res}(z=a)=\frac{1}{(n-1)!}\left\{\frac{d^{n-1}}{dz^{n-1}}[(z-a)^n f(z)\right\}_{z=a}$

- **Residue theorem**

$\oint_c f(z)dz=2\pi i\times$(sum of residue at poles inside or on c)

Probability of statistics

$P(E) = \dfrac{\text{Favourable events}}{\text{Total number of events}} = \dfrac{n(E)}{n(S)}$

- Mutually exclusive events → $P(A \cap B) = 0$
- Independent events → $P(A \cap B) = P(A).P(B)$
- Conditional probability → $P\left(\dfrac{E_1}{E_2}\right) = \dfrac{P(E_1 \cap E_2)}{P(E_2)}$
- $0 \le P(E) \le 1$
- Probability density function (PDF) - Let x be continuous random variable then its PDF f(x) is defined as - $\int_{-\infty}^{\infty} f(x)dx = 1$
- $P(\bar{E}) = 1 - P(E)$
- $P(E_1 \cup E_2) = P(E_1) + P(E_2) - P(E_1 \cap E_2)$
- $P(\bar{E}_1 \cap \bar{E}_2) = P(\overline{E_1 \cup E_2}) = 1 - P(E_1 \cup E_2)$
- Mean $\bar{x} = \dfrac{a+b}{2}$
- If X & Y are independent random variable then $\mathrm{Var}(X+Y) = \mathrm{Var}\,X + \mathrm{Var}\,Y$
- Var X= $E(X^2)$- $[E(X)]^2$
- Var $(cX) = c^2.\mathrm{Var}(X)$
- Standard deviation, $\sigma = \sqrt{\text{variance}}$

Binomial distribution	**Poisson Distribution**
$P(r) = {}^nC_r P^r q^{n-r}$	$P(r) = \dfrac{m^r e^{-m}}{r!}$ $\boxed{m \to \text{mean}}$

- **Normal Distribution** $\boxed{f(x) = \dfrac{1}{\sqrt{2\pi\sigma}} e^{-\frac{(x-\mu)^2}{2\sigma^2}}}$
- **Exponential Distribution** $f(x) = \begin{cases} \lambda e^{-\lambda x} & x \ge 0 \\ 0 & x < 0 \end{cases}$

Numerical Method

Name of Method	**Formula**
Trapezoidal rule	$\int_{x_0}^{x_0+nh} f(x)dx = \dfrac{h}{2}[(Y_0 + Y_n) +$ $2(Y_1 + Y_2 + ...Y_{n-1})$
Simpson's $\frac{1}{3}$ rule	$\int_{x_0}^{x_0+nh} f(x)dx = \dfrac{h}{3}[(Y_0 + Y_n) +$ $4(Y_1 + Y_3 + ...Y_{n-1}) + 2(Y_2 +$ $Y_4 + ...Y_{n-2})$
simpson's $\frac{3}{8}$ rule	$\int_{x_0}^{x_0+nh} f(x)dx = \dfrac{3h}{8}[(Y_0 + Y_n) +$ $3(Y_1 + Y_2 + Y_4 + Y_5 + ... + Y_{n-1}) +$ $2(Y_3 + Y_6 + ...Y_{n-3})$
Weddle's Rule	$\int_{x_0}^{x_0+nh} f(x)dx = \dfrac{3h}{10}[Y_0 + 5Y_1 +$ $Y_2 + 6Y_3 + Y_4 + 5Y_5 + 2Y_6 +$ $5Y_7 + Y_8 + ...$
Bisection Method	$x_0 = \dfrac{a+b}{2}$
Newton-Raphson method	$x_{n+1} = x_n - \dfrac{f(x_n)}{f'(x_n)}$
Regula- Falsi method	$x_{n+1} = \dfrac{f_n X_{n-1} - f_{n-1} X_n}{f_n - f_{n-1}}$
Secant method	$x_2 = \dfrac{f_1 x_0 - f_0 x_1}{f_1 - f_0}$
Euler's Method (Runge-kutta first order)	(i) $Y_{n+1} = Y_n + hf(x_n, y_n)$. → forward (ii) $Y_{n+1} = Y_n + hf(x_{n+1} Y_{n+1})$. → Backward
Runge -Kutta method(4th order)	$y_{n+1} = y_n + K$ and $x_{n+1} = x_n + h$ $K = \dfrac{1}{6}(K_1 + 2K_1 + 2K_3 + K_4)$ $K_1 = hf(x_n, y_n), K_2 =$ $hf\left(x_n + \dfrac{h}{2}, y_n + \dfrac{K_1}{2}\right)$ $K_3 = hf(x_n + \frac{1}{2}h, y_n + \frac{1}{2}K_2)$ $K_4 = hf(x_n + h, y_n + K_3)$

☞ Remember point

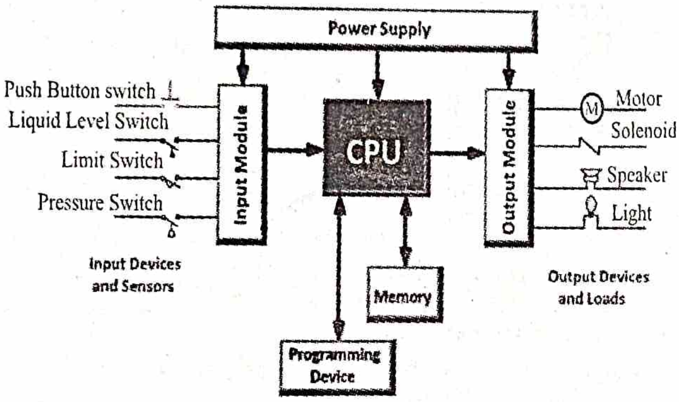
Method	**Speed**	**Convergence**	**Order**	**No. of Guess**
Bisection	Slower	Converges	1	2
Secant	Medium	May or may not be converges	1.62	2
Newton-Raphson	Faster	May or may not be converges	2	1

PLC, SCADA AND AUTOMATION

- **PLC (Programmable Logic controller):** A PLC is a computer specially designed to work in an industrial environments such as extreme temperatures, wet, dry and dusty conditions.

A PLC is capable of operating in corrosive atmosphere and can also withstand to shock and vibrations. PLC is such a physical device, which controls industrial operation automatically with the help of 'logic program' i.e. a PLC is a digitalized computer which can be programmed or reprogrammed by programmer.

- **Typical block diagram of PLC is -**



Programmable Logic Controller or PLC Block Diagram

- **Parts of PLCs are –**

Power supply	It provides the supply to all devices such as CPU, Memory, I/O module. For I/O modules, we needs a separate power supply of 12V/24V DC while for CPU or microprocessor needs 5V DC supply. **Note:-** Input devices or sensor can't operate with 5V DC that's why 12V/24 V DC is provided.
CPU (Processor)	It is the main part of PLC. It processes all the instructions required for working of the circuit. First, we store the program or instruction in memory. In the operation time, the CPU takes the commands from the input module and then process and ultimately gives the output to the output module. **Note:-** • CPU is known as the brain of PLC. • CPU monitors the inputs and makes decision in a PLC.
Memory	It is a storage device which stores all data, programs and instructions. **Note:-** • A PLC memory has capability to store from 1 KB to 64 KB. • Executive memory is used to monitors program and user memory is used to stores the program code.
Input/Output Module	These modules are used for connecting the processor to the field devices. **(i) Input module-** It provides the interfacing between input and CPU. **(ii) Output module-** It provides the interfacing between output and CPU.
Programming Device	It is the device where the program or instruction is written and by using this device the program or instruction is stored to the PLC's memory. **Note:-** The programming device may be a computer, laptop etc.

- **Input and output devices used in PLCs are–**

Input Devices	Output Devices
Limit switches, Proximity sensors, Photoelectric sensors, Condition sensors	Solenoids, Control relays, Valves
Float switches	Alarm, Light, Horns

Pressure switches	LED display
Sensors	Heat coil, Motors
Encoders	Contractors
Level switches	Pumps

- **PLC Brands, Software are country:-**

PLC Brands	Software	Country
Honeywell	HRA, soft master	American
Siemens	Simatic step 7	European
Omron	CX Programmer	Japanese
Mitsubishi	MELSOFT series	Japanese
ABB	ACO10/AC 500	European
Allen-Bradley	RS Logix 500	American
General Electric	Durus	American
Bosch	Bosch Rexrot	European
Hitachi	EH-150, Pro-H	Japanese

Types of PLC Programming Languages

Graphical Language
(1) Ladder Diagram (LD)
(2) Function Block Diagram (FBD)
(3) Sequential Function chart (SFC)

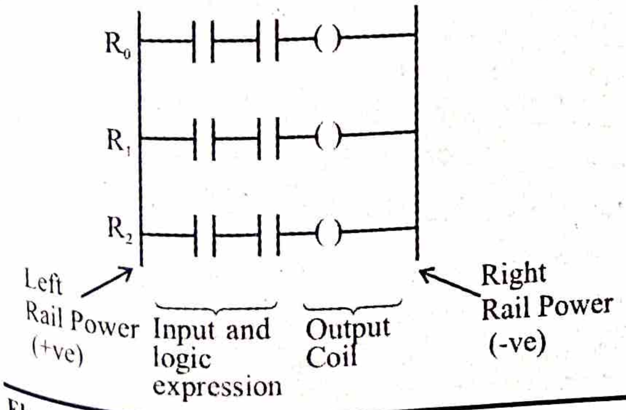
Textual Language
(1) Instruction List (IL)
(2) Structured Text (ST)

Note:-

- Ladder diagram or Ladder logic is the oldest programming languages and it is mostly used.
- SFC (Sequential Function Chart) is based on flow chart concept.
- Structured text programming language utilizes statements to determine what to execute.

- **Ladder Diagram (LD):-** It is known as 'relay ladder logic' and this language is mostly used. Ladder logic is very cost effective language and has a excellent graphical representation of circuit design concept.

- **Ladder logic diagram –**



- **Rungs:-** It is Horizontal line which 'connects rail to logic expression'.
- **Rails :-** It is vertical line which represents the supply wire of a relay logic circuit.

Note:-

- Rail represent the start and end of each line in ladder diagrams.
- In ladder diagram language output is represented by 'Relay coil'.
- Ladder logic programming consists of a 'virtual relay contacts and coils'.

Some important points related to Ladder logic:-

- In Ladder logic NO (Normally Open) and NC (Normally Close) are mainly used to define 'digital inputs and internal logic instructions'.
- A coil in Ladder logic defines 'digital output'.
- In Ladder logic, PLC scans each rung left to right and top to bottom.
- There should be at least one input or logic expression to start of each rung and there should be at least one output at end of each rung.

- **PLCs Programming Contacts:-**

(1) Normally Open (NO), —| |— A

(2) Normally Close (NC), —|/|— $\bar{A}$

Power flows through these two contacts, when they are closed i.e. NO and NC changes according to the given logic.

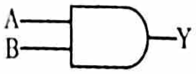
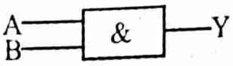
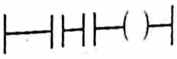
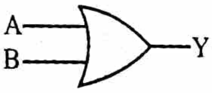
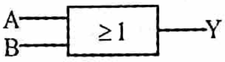
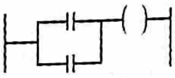
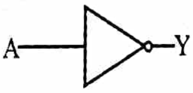
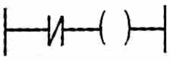
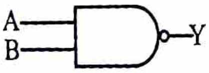
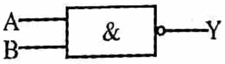
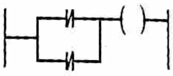
Note:- There are mainly three symbols used in PLC that is NO, NC and output coil while remaining other uses with them.

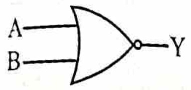
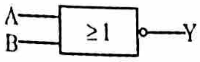
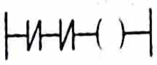
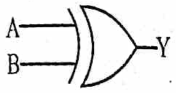
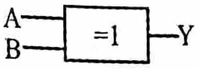
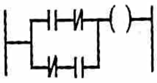
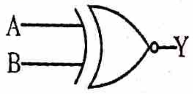
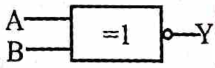
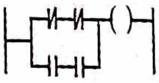
—| |— A, NO (Normally Open) or logic 0

—|/|— $\bar{A}$, NC (Normally Close) or logic 1

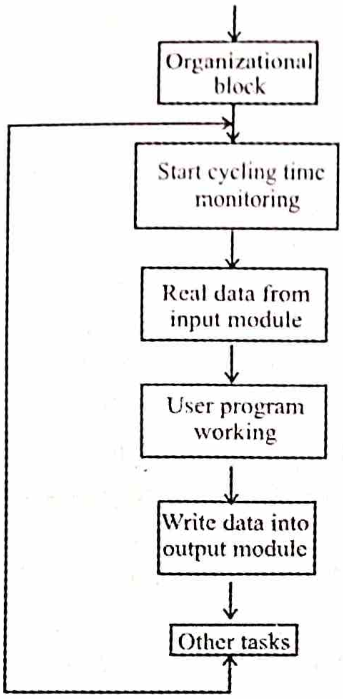
—(Q)—, Relay coil or Output coil.

If NO (Normally Open) is operating on low logic (logic 0) and if high logic (logic 1) is given to NO then it works as NC (Normally Close) and vice-versa.

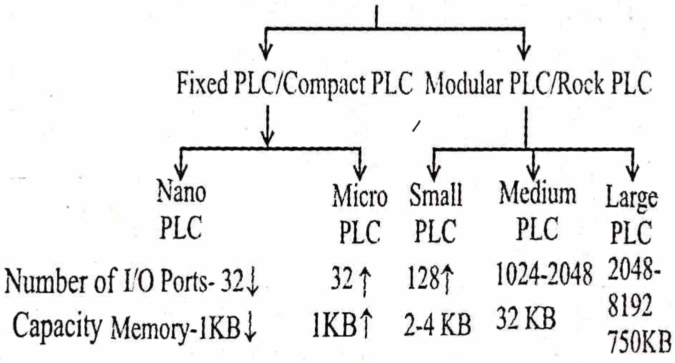
Logic Gates	Logic symbols	Truth Tables	Functional Block Diagram/IEC symbols	Ladder Logics	Description About Gates	Description About Ladder Logics
AND		A B $Y=A\cdot B$ 0 0 0 0 1 0 1 0 0 1 1 1			In 'AND gate', the output is high (logic 1) when all the inputs are high (logic 1) otherwise the output is low (logic 0).	'AND Function' in ladder logic uses 'Normally open contracts in series'.
OR		A B $Y=A+B$ 0 0 0 0 1 1 1 0 1 1 1 1			In 'OR gate', the output is high (logic 1) when one or more of its inputs are high (logic 1). If all the inputs are low (logic 0) then output is low (logic 0).	'OR Function' in ladder logic uses 'Normally open contacts in parallel.
NOT		A $V=\bar{A}$ 0 1 1 0			In 'NOT gate', the output is low (logic 0) when its input is high (logic 1) and vice-versa.	'NOT Function' in ladder logic uses 'Normally close contact in series with output coil.
NAND		A B $Y=\overline{AB}$ 0 0 1 0 1 1 1 0 1 1 1 0			In 'NAND gate' the output is low (logic 1) when its all inputs are high (logic 1) otherwise the output is high (logic 1)	'NAND Function' in ladder logic uses 'Normally close contact in parallel

NOR		A B $Y=\overline{A+B}$ 0 0 1 0 1 0 1 0 0 1 1 0			In 'NOR gate', the output is high (logic 1) when all inputs are low (logic 0) otherwise the output is low (logic 0).	'NOR Function' in ladder logic uses 'Normally close contact in series.
EX-OR		A B Y⊕B 0 0 0 0 1 1 1 0 1 1 1 0			In 'Ex-OR gate', the output is high (logic 1) when one and only one of its input is high (logic 1) otherwise the output is low (logic 0)	'EX-OR Function' in ladder logic uses series connection of Normally open and Normally close contact in parallel with series connection of Normally close and Normally open contacts.
EX-NOR		A B $Y=\overline{A\oplus}$ 0 0 1 0 1 0 1 0 0 1 1 1			In 'EX-NOR gate', output is high (logic 1) when its both inputs are same.	'EX-NOR Function' in ladder logic uses series connection of two Normally close contacts in parallel with series connection of two Normally open contacts.

- **PLC Scan Cycle is –**


Organizational block
Start cycling time monitoring
Real data from input module
User program working
Write data into output module
Other tasks

- **There are mainly two types of PLC :-**


Fixed PLC/Compact PLC
Modular PLC/Rock PLC
Nano PLC
Micro PLC
Small PLC
Medium PLC
Large PLC
Number of I/O Ports- 32↓
32↑
128↑
1024-2048
2048-8192
Capacity Memory-1KB↓
1KB↑
2-4 KB
32 KB
750KB

- **Fixed PLC/compact PLC :-** It has a fixed number of I/O modules and external I/O Module. So, it does not have the capability to expand the modules.
- **Modular PLC :-** It can be extended the range of I/O Module with the help of 'Racks' so, this is also known as 'Rack PLC'.
- **Difference between Compact and Modular Type PLCs are–**

Compact	Modular
Input capability is fixed and determined by the manufacture.	It can expand the capacities of input.
They are used for small scale I/O port	They are used for large scale I/O port.
A Compact PLC is a cheaper than modular PLC and it is used for performing stand alone tasks.	A Modular PLC is costly than compact PLC, and consists of multiple modules.
Compact PLC are self contained units, they are difficult to repair.	In Modular PLC Individual blocks are easier to repair since this does not affect the entire system as a whole.

Some facts about PLCs are –

- First PLC was invented by 'Dick Morley' in 1964.
- First PLC model is 'MODICON 084' was invented by 'Dick Morley in 1969.
- First commercial PLC was invented by 'Michael Greenburg' in 1973, which model is '184'
- A PLC is a μp based device so, processor (CPU) is called as a brain of PLC, and the primary function of CPU is to 'read input, control and update output'.
- A PLC is a solid state rugged construction, Hardware device.
- A PLC controller can be executed or operated by automatically or manually.
- PLC has become popular because it performs 'Timing and counting functions'.
- For PLC the sequence of scan is 'Read, execute and write'.
- A PLC operates on digital signals.
- A PLC can understand both 'analog and binary signals'.
- PLC used to control machines and processes.
- Generally PLC provides 'close loop system' because automation is achieved only in close loop system.
- PLC's analog I/O address value has '1 word' i.e. 16 bits.
- Execution, read and write process is the part of PLC during operation or during run mode but entry and editing of program is not possible.
- In a PLC, online programming means a program which 'resides in the PLC' and offline programming means a program which 'resides in the PC or Laptop'.
- The PLC function which generates output signals according to logical operations performed on input signals are known as 'control relay functions'
- In PLC programming, a retentive function is one that 'is not reset after a power cycle'.
- The use of JMP (Jumped Instruction Paired) instruction in PLC is 'causing PLC to skip over rungs'.

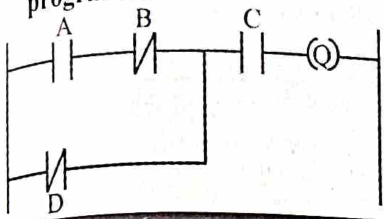
Note:-

Programmable Logical Controller (PLC) are the device that were invented basically to replace 'Relays', which is made of coils.

- **Advantages of PLC over electromechanical relay (Relay logic) :-**

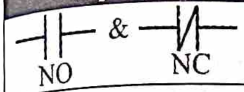
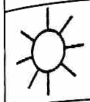
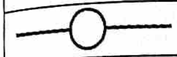
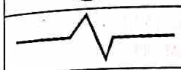
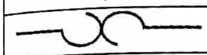
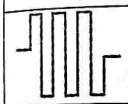
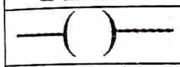
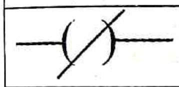
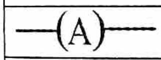
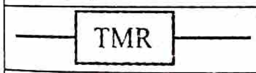
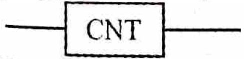
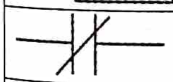
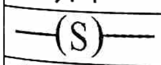
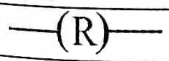
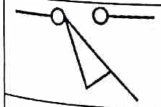
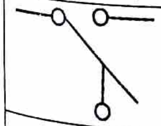
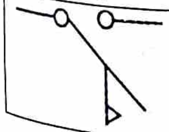
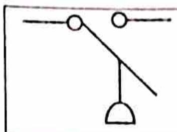
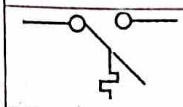
- They are designed for an electrically noisy environment, so no extra filtering is required.
- Easier and faster to make change.
- They are smaller, faster and more reliable than hardwired (electromechanical relay) system.
- The output may be a mixture of conventional relays and solid-state relays.
- Low operating cost.

- **The Boolean representation of the PLC program is:-**



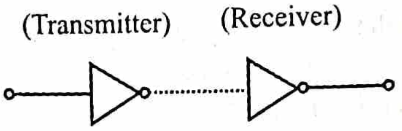
$\Rightarrow (A\bar{B} + \bar{D}) \cdot C$

Important symbols used in PLCs are:-

	NO & NC
	Indicator lamp
	Relay coil
	Solenoid coil
	Thermal overload relay
	Heating element
	Output
	Not output
	Alarm
	Timer
	Counter
	Overload
	Set
& 	Reset.
	Limit switch
	Level switch
	Flow switch
	Pressure switch
	Temperature switch

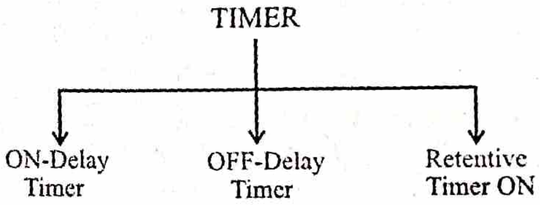
- **RS232-** RS232 is a communication interface standard initially used in Telephone data communication.

- In RS232 maximum number of transmitters and receiver are one.
- In RS232 maximum line length 15m.



logic1 = –15 to –3volt
logic 0 = + 3 to + 15 volt

Timer in PLC

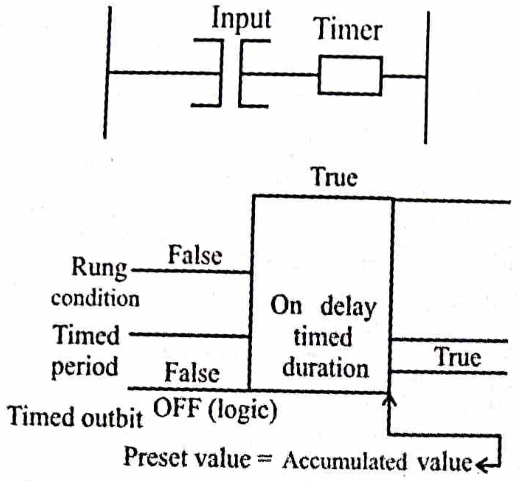


T-ON (Timer ON-Delay)	Counts time-based intervals when the instructions is true.
T-OFF (Timer OFF-Delay)	Counts time-based intervals when the instruction is false.
RTO (Retentive Timer ON)	Count time-based intervals when the instructions is true and retains the accumulated value when the instruction goes false or when power cycle occurs.

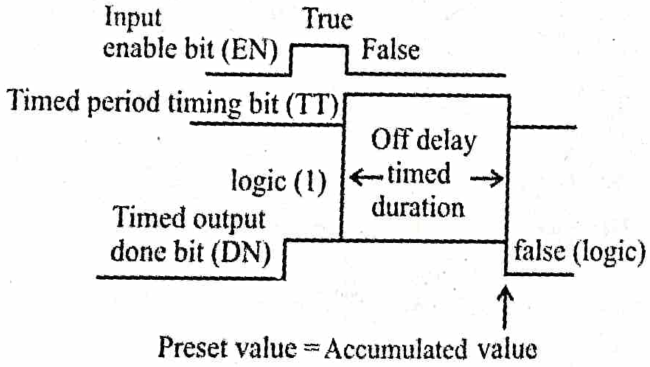
- **Terms represented in the timer block-**

Timer base	It means interval that the timer is going to use.
Preset	It means the delay period timer.
Accumulated	Current delay of timer.
Timer number	The timer file name

- **Operation figure of ON Delay Timer-**

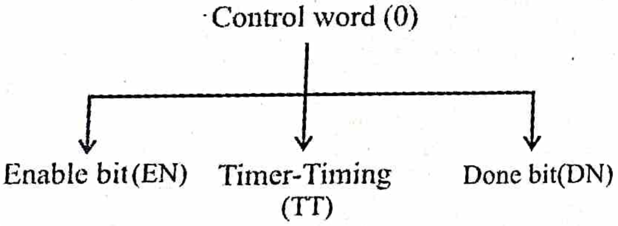

Input
Timer
True
Rung
condition
False
Timed
period
False
On delay
timed
duration
True
Timed outbit
OFF (logic)
Preset value = Accumulated value

- **OFF-Delay Timer Operation figure-**

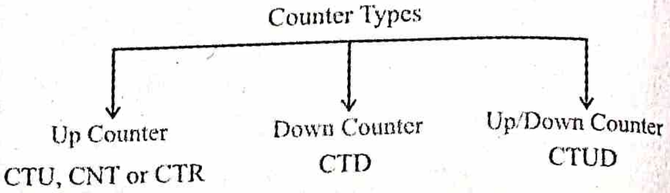

Input
enable bit (EN)
True
False
Timed period timing bit (TT)
Off delay
timed
duration
logic (1)
Timed output
done bit (DN)
false (logic)
Preset value = Accumulated value

- **Control words in PLC Timer-**

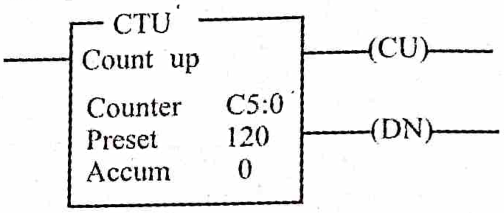
Word 0	EN TT DN
Word 1	Preset Value
Word 2	Accumulated Value


Control word (0)
Enable bit(EN)
Timer-Timing
(TT)
Done bit(DN)

- **Enable bit (EN)-** The enable bit is true (has a status of 1) whenever the timer instruction is true and when the timer instruction is false, the enable bit is false (has a status of 0).
- **Timer-timing (TT)-** The timer-timing bit is true whenever the accumulated value of timer is changing, which means the timer is timing. When the timer is not timing, the accumulated value is not changing so the timer-timing bit is false.
- **Done (DN) bit-** The done bit changes state whenever the accumulated value reaches preset value. Its state depends on the type of timer being used.
- **Control word (1) (Preset value)-** Preset value of word is the set point of timer is that the value up to which the timer will time. The preset word has range of 0 through 32767 and it stored in binary form. The preset will not store a negative number.
- **Control word (2)- (Accumulated value)-** The accumulated word is the value that increment as timer in timing, the accumulated value will stop incrementing when its value reaches preset value.
- **Counter Instruction-** Typically counters can count from 0 to 9999, –32768 to +32767 or 0 to 65535


Counter Types
Up Counter
CTU, CNT or CTR
Down Counter
CTD
Up/Down Counter
CTUD

- **Count up counter-**


CTU
Count up
Counter C5:0
Preset 120
Accum 0
(CU)
(DN)

➢ Each time rung condition changing from false to true.

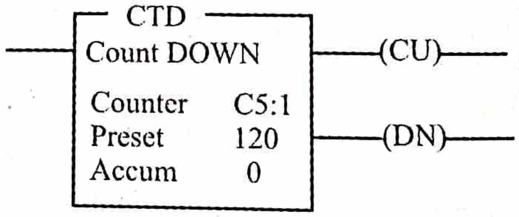
➢ When a counter up is counting, its CU bit high.

➢ DN bit high when Accumulate value greater or equal to preset value.

- **Count-down counter-**

➢ Each time rung condition count when rung condition true to false.

➢ DN bit high when Accumulated value ≥ Preset value


CTD
Count DOWN
Counter C5:1
Preset 120
Accum 0
(CU)
(DN)

- **Up/Down Counter (CTUD)-**

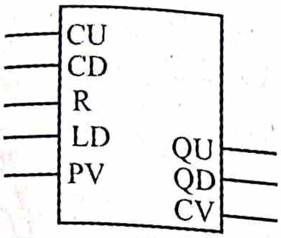
➢ Every +Ve edge on CU increment CV by 1

➢ Every +Ve edge on CD decrement CV by1

CV	QD	QD
CV< =0	1	0
CV>=PV	0	1

➢ R : Reset counter

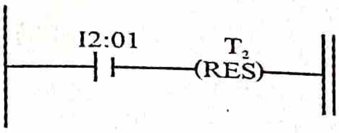
➢ LD : Load CV with the value PV


CU
CD
R
LD
PV
QU
QD
CV

Count up/ Down Counts

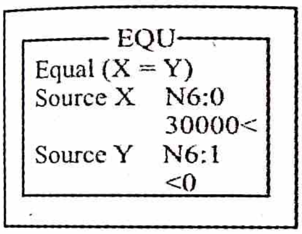
☐ **The Reset (RES) Instruction-** The RES instruction reset counting Instruction when the RES instruction is enabled it resets the following–

- **Counters-**
  i. Accumulated Value **ii.** Counter Done Bit
  iii. Counter Enabled Bit
- **Timers-**
  i. Accumulated value **ii.** Timer Done Bit
  iii. Timer Timing Bit **iv.** Timer Enable Bit
- **Reset Ladder Diagram example-**

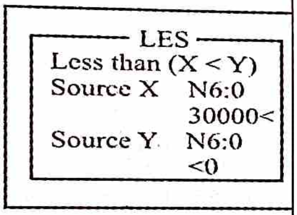


- **Comparison Instruction PLC**

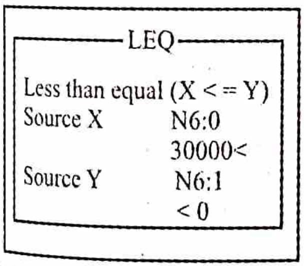
EQU= Equal


EQU
Equal (X = Y)
Source X N6:0
30000<
Source Y N6:1
<0

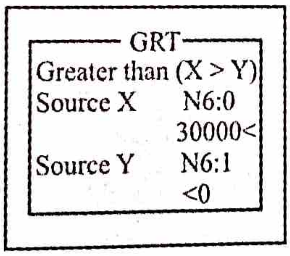
LES= Less than


LES
Less than (X < Y)
Source X N6:0
30000<
Source Y N6:0
<0

LEQ= Less than or Equal

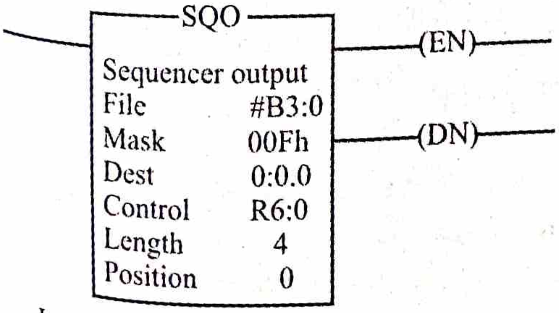

LEQ
Less than equal (X <= Y)
Source X N6:0
30000<
Source Y N6:1
< 0

GRT= Greater than


GRT
Greater than (X > Y)
Source X N6:0
30000<
Source Y N6:1
<0

☐ Sequencer Instruction

- **SQO-** Sequence Instruction (SQO) is an output Instruction.


SQO
Sequencer output
File #B3:0
Mask 00Fh
Dest 0:0.0
Control R6:0
Length 4
Position 0
(EN)
(DN)

In the above Block we have Six parameters.

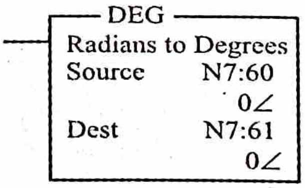
- **File-** The file is the address of sequencer file. The file indicator (#) for the address must be used.
- **MASK-** The mask is a hexadecimal code or the address of the mask word or file through which the instruction moves data. Masks bit can be set to pass data and reset to mask data. If you want to change the mask according to application requirements you can use a mask word or file. If the mask is a file, its length will be equal to the length of sequencer file.
- **Dest-** Address of the output word or file for a SQO to which the Instruction data from its sequencer.
- **Control-** To control parameter structure do the following, store the status byte of the Instruction, length of sequencer file, and the instantaneous position in file. The control address can not be used for any other instruction.
- **Length-** The length is the number of steps of the sequencer file starting at position 1. The maximum number of words is 255(in micrologix 1000 controllers the max is 104 words.)
- **Position -** The position is the word location or step the sequencer file from/to which the instruction move data.

- **Other sequencer Instruction-**

a. Sequencer Load (SQL)
b. Sequencer Input (SQI)
c. Sequencer compare (SQC)

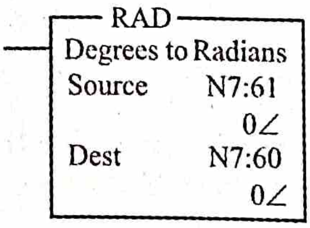
☐ **Data handling instruction**

- **Radian to degrees (DEG)-**

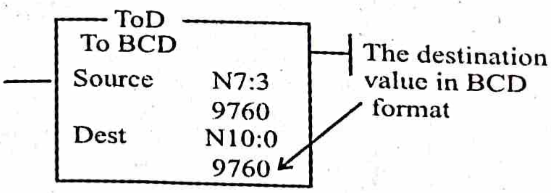

DEG
Radians to Degrees
Source N7:60
0∠
Dest N7:61
0∠

$$\text{DEG} = \frac{\text{Source}\times 180}{\pi}$$

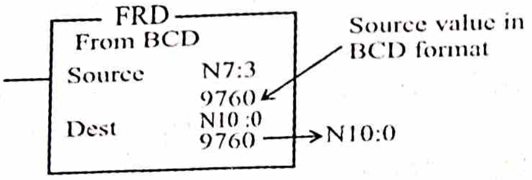
- **Degrees to Radians (RAD)-**


RAD
Degrees to Radians
Source N7:61
0∠
Dest N7:60
0∠

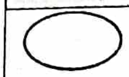
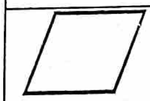
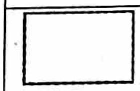
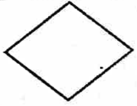
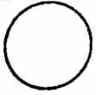
- **Convert to BCD (ToD)-**


ToD
To BCD
Source N7:3
9760
Dest N10:0
9760
The destination value in BCD format

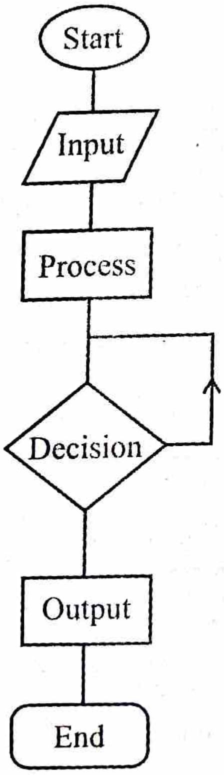
- **Convert from BCD to FRD-**


FRD
From BCD
Source
N7:3
9760
Dest
N10 :0
9760
N10:0
Source value in
BCD format

Flow Charts-

Symbols	**Names**	**Use in flow chart**
	Oval	Represents 'start and end points'.
	Parallelogram	Represents 'Input and Output points'.
	Rectangle	Represents to 'Process'.
	Diamond	Represents to 'Decision'.
	Arrow	Represents the direction of logic flow in a program
	Circle	Represents to connector.

Example of Flow chart:-

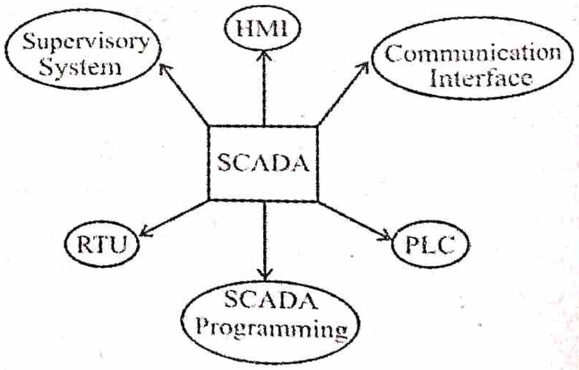

Start
Input
Process
Decision
Output
End

☞ **Remember point**

- ➢ Time base timer parameters determines the accuracy of the timer.
- ➢ Preset timer parameter determines the duration for the timing circuit
- ➢ Accumulated time timer parameter represents the value that increment as the timer is timing.
- ➢ The visual programming language also called Ladder logic.
- ➢ Logic functions of PLC programming are "YES" "AND", "OR" NOT" and "INHIBITION".
- ➢ The simplest form of PLC programming, also known as relay ladder diagram.
- ➢ For a 16 bit register largest integer number of a PLC counter function can reach is 65535.
- ➢ Maximum number of Inputs and outputs that are in a small PLC 128.
- ➢ Structure text programming is a programming language that utilizes statement to determine what to execute.

■ **SCADA-**SCADA (Supervisory Control And Data Acquisition) is used by manufactures across numerous industries and applications to remotely monitor and automatic control of industrial processes and machines.

- **SCADA Block Diagram**


Supervisory System
HMI
Communication Interface
SCADA
RTU
PLC
SCADA Programming

- **SCADA Consists of five main components, outlined below:**

a. Field instrumentation
b. Field controllers (RTUs/PLCs)
c. Human-Machine Interface
d. Network Connectivity (field Buses, Protocols, etc)
e. Database or historian (Cloud or on-premise)

Field instrumentation	A field instrumentation can be a sensor, flowmeter, or anything else that monitors the process.
Field Controllers (RTUs/PLCs)	RTUs and PLCs collect and complete data supplied by field instrumentation, preparing it for display and analysis by the human-machine interface.
Human Machine Interface (HMI)	HMI devices are master units that allow human to supervise the SCADA data acquisition process.
Network Connectivity (field buses, protocols, etc)	The SCADA system relies on maintaining integrated network connectivity throughout its operation.
Database or historian	After analyzing and processing the data gathered by your SCADA systems you need physically and digitally secure places to store it.

- **Generation of SCADA System:**

1. First Generation: Monolithic or Early SCADA systems-
2. Second Generation: Distributed SCADA system
3. Third Generation: Networked SCADA systems
4. Fourth Generation: internet of things technology, SCADA systems.

- **SCADA Brands and its softwares:-**

SCADA Brands	**Softwares**
Rockwell	RSview 32
Siemens	WinCC
GE Digital	Crimplicity
Wonderware	In Touch

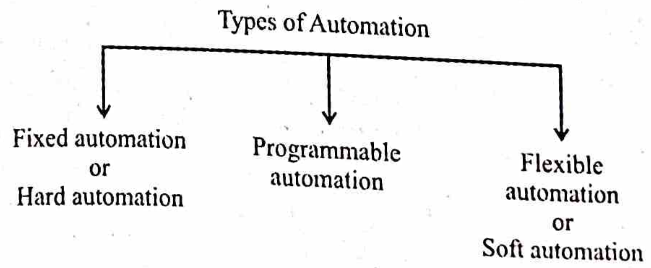
Full form names related to PLC and SCADA:-

SIMATIC	Siemens Automatic
ABB	Asea Brown Boveri
MODICON	Modullar Digital Controller
DCS	Distributed Control System
HMI	Human Machine Interface
PID	Proportional Integral and Differential
PIT	Pressure Indicating Transmeter.
RTUs	Remote Terminal Units.
MTVs	Master Terminal Units.
DTE	Data Terminal Equipment
DDE	Dynamic Data Exchange
GUI	Graphical User Interface.
MVM	Masked Move.

- **Comparison Between PLC and SCADA :-**

PLC	**SCADA**
PLC stands for 'Programmable Logic Controller'.	SCADA stands for 'Supervisory Control And Data Acquisition'.
It is a Hardware device .	It is a software device.
It is used to control or operate the system .	It is used to control and monitor the system.
Processor (CPU) is known as 'Brain' of PLC.	I/O task is known as 'Heart' of SCADA.
It discovered by 'Allen bradley' in 1964.	It started in 1960 and firstly used for weather forecasting
'ICC 61131-3' defines about software language in PLC	'ICC 61850' is related to SCADA software.
Use of PLC :- •Driving motors •Light Lamps •Traffic signals •Robotics •Textile Mills	Use of SCADA :- •Food processing Industry •Oil and Gas Control System. •Power System •Manufacturing Plants.

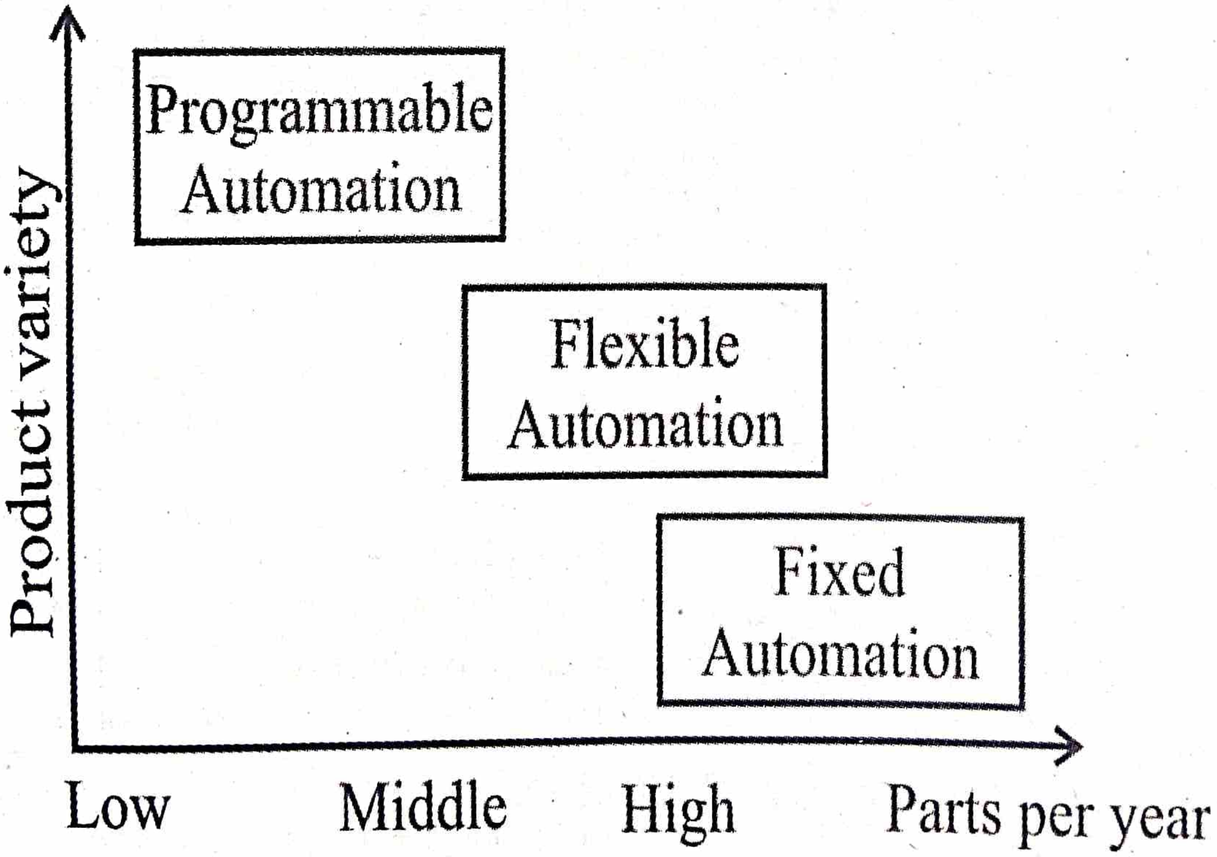
■ Automation


Types of Automation
Fixed automation or Hard automation
Programmable automation
Flexible automation or Soft automation

- **Automation Comparison-**

Automation	Consideration	Advantages	Disadvantages
Fixed/hard	• High demand value • Long product cycle	• Maximum efficiency • Low unit • Automated material handling-fast and efficient movement of parts	• Large initial investment • Inflexibility
Programmable	• Batch production • Products with different options	• Flexibility to deal with changes in product • Low unit cost for large batches	• New product requires long setup time • High unit cost relative to Fixed automation
Flexible/Soft	• Low production rates • Varying demand • Short product life cycle.	• Flexibility of deal with variations • Customized products.	• Large initial investment • High unit cost relative or programmable automation

- **Automation in production system-**


Product variety
Programmable Automation
Flexible Automation
Fixed Automation
Low
Middle
High
Parts per year

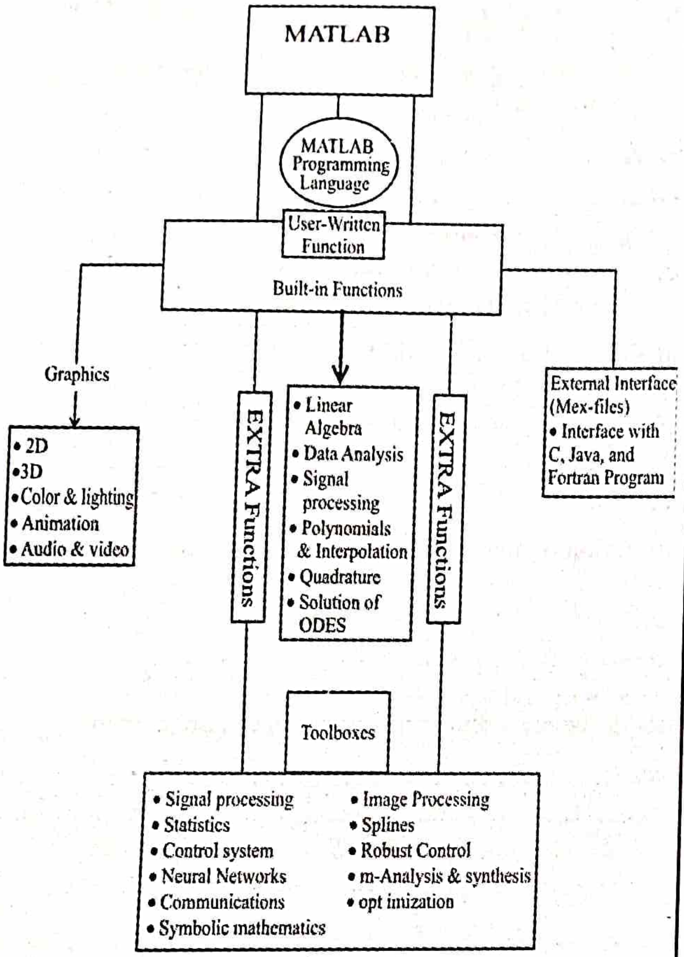
COMPUTER FUNDAMENTAL AND APPLICATION OF COMPUTER SOFTWARE

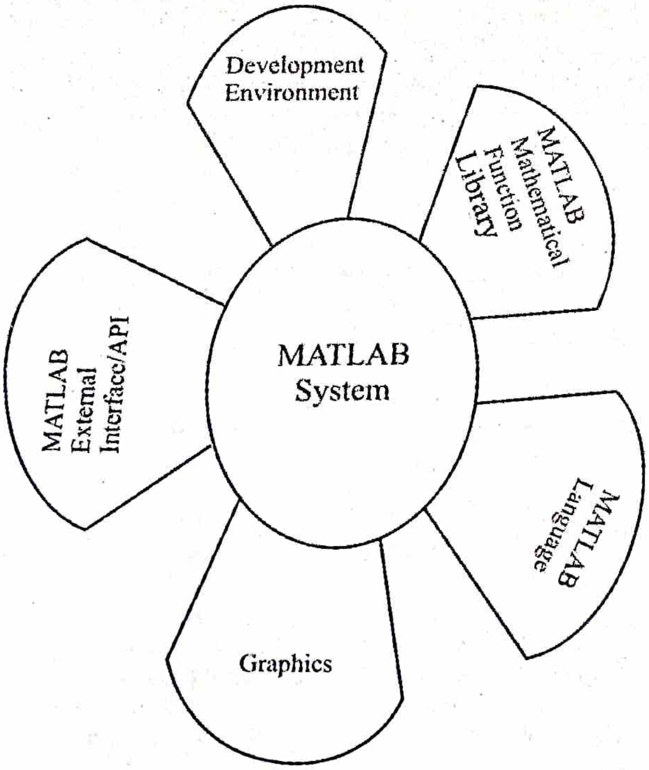
Use of Software in Electrical Engineering

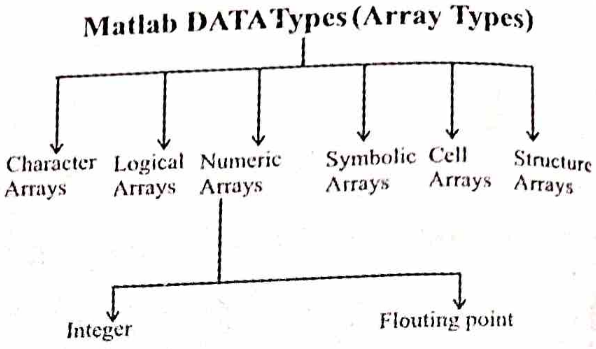
Software	Used
MATLAB (MATrix LABoratory)	it helps to perform, design, analysis and optimization. This is performing and numeric computing platform.
Simulink	Simulate, analyze, renewable energy resources, transmission lines, electrical transients, stand by switching of power supply.
Pspice (Personal Simulation Program with Integrated Circuit Emphasis)	Simulation and verification of analog and mixed-signal circuits.
ETAP (Electrical Transient Analyzer Program)	Power flow Analysis, Relay coordination protection design, control system design optimal power flow.
Power world Simulator	Simulate high voltage power system operation on a time frame ranging from several days.
Multisim	SPICE Simulation, analysis and PCB (Printed cricuit Board) tools to help quickly interate through designs and improve prototype performance.
PSCAD (Power System Computer Aided Design)	Design, analyze, optimize and Verify power electronic control and systems.
LabVIEW (Laboratory Virtual Instruments Engineering Workbench)	develop automated research, Validation, and product test systems. test, measurement and control with rapid access to hardware and data insights.
Keil Microvision	• Debugging program • Compiling and Assembling programs • Creating Hex and Axf file
PSS/E (Power system simulator for engineering)	Simulate electrical power transmission networks in steady-state conditions as well as overtime Scale of a few seconds to tens seconds.

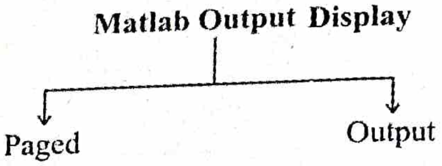
■ MATLAB

■ A schematic diagram of MATLAB-


MATLAB
MATLAB Programming Language
User-Written Function
Built-in Functions
Graphics
• 2D
•3D
•Color & lighting
• Animation
• Audio & video
EXTRA Functions
• Linear Algebra
• Data Analysis
• Signal processing
• Polynomials & Interpolation
• Quadrature
• Solution of ODES
EXTRA Functions
External Interface (Mex-files)
• Interface with C, Java, and Fortran Program
Toolboxes
• Signal processing
• Statistics
• Control system
• Neural Networks
• Communications
• Symbolic mathematics
• Image Processing
• Splines
• Robust Control
• m-Analysis & synthesis
• opt imization


Development Environment
MATLAB Mathematical Function Library
MATLAB External Interface/API
MATLAB System
MATLAB Language
Graphics


Matlab DATATypes (Array Types)
Character Arrays
Logical Arrays
Numeric Arrays
Symbolic Arrays
Cell Arrays
Structure Arrays
Integer
Flouting point


Matlab Output Display
Paged
Output

☐ MATLAB WINDOWS-

i. MATLAB Desktop
ii. Figure Window
iii. Editor Window

☐ Main MATLAB Commands-

- **Directory Information-**

Command	Function
pwd	shows the current working directory
cd	Changes the current working directory
dir	lists contents of current directory
ℓs	lists contents of current directory
path	get or sets MATLAB search path
editpath	modifies MATLAB search path
copy file	Copies a file
mkdire	Creates a directory

- **Matrix Functions**

eye	Identity of matrix
zeros	Matrix of zeros
ones	Matrix of ones
diag	Extract diagonal of a matrix or matrices create diagonal matrices
triu	Upper triangular part of a matrix
rand	Randomly generated matrix
size	Size of a matrix
det	Determinant of a square matrix
inv	Inverse of a matrix
rank	Rank of a matrix
eig	Eigenvalues and eigen vectors
poly	Characteristic polynomial
tril	Lower triangular part of a matrix

◻ Built in Function of MATLAB

- **Scalar Functions-**

sin	trigonometric sine
cos	trigonometric cosine
tan	trigonometric tangent
a sin	trigonometric Inverse sine
a tan	trigonometric inverse tangent
exp	exponential
log	natural logarithm
abs	absolute value
sqrt	squre root
rem	reminder
round	round towards nearest integer
floor	round towards negative infinity
ceil	round towards positive infinity

- **Vector functions-**

Min	smallest component
length	length of a vector
Sort	sort in ascending order
Sum	sum of elements
Prod	Product of element
Median	median value
Mean	mean value std standard deviation
Max	largest component :get the row in which the maximum element dies.

- **On-line help-**

help	lists topics on which help is available
helpwin	opens the interactive help window with a default list
doc	Opens the web browser-based help facility
look for string	lists help topics containing string
demo	runs the demo program

- **General information**

computer	Tells you computer type you using
clock	Gives you wall clock time and date as a vector
date	Tells you the data as a string
more	Control the paged output according to the screen size
ver	Gives the license and the MATLAB version information
bench	Benchmarks your computer on running MATLAB compared to other computers.

- **Workspace Information**

who	Lists variable currently in workspace
whos	List variable currently in the workspace with size
what	List, M-, MAT,-and Mex-files on the disk
clear	Clears the workspace, all variables removed
clear xyz	Clears only variables x,y,z
clear all	Clears all variable and function from workspace
clc	Clears Command window, cursor moves to the top
home	Scrolls the command window to put the curser on top
clf	Clears figure window.

(3) Termination-

control+C	Local abort, kills the current command execution
quit	quits MATLAB
exit	Similar to quit
control +B	Similar to (Control + c)

- **MATLAB FILES**

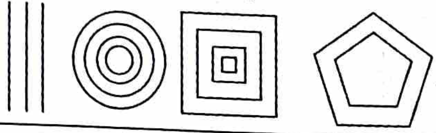
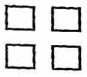
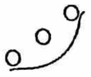
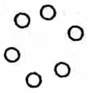
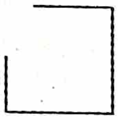
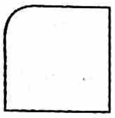
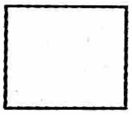
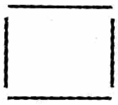
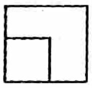
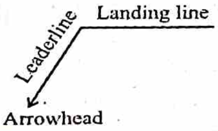
M-files	M-files are standard ASCII text files, with a .m extension to the file name.
Mat- files	Mat-files are binary data files with a .mat extension to the file name
Fig- files	Fig-files are binary figure files with a .fig extension that can be opened again in MATLAB as figures.
P-files	P-files are compiled M-files with a.p extension.
Mex-files	Mex-files are MATLAB-Callable c, Fortran, or Java Programs, with a. mex extension to the filename.

☞ Remember point

- ➢ Four generation of programming language used by MATLAB Software.
- ➢ Numerical, Algebraic, Dynamic system analysis done by MATLAB Software.
- ➢ Script window is called Editor window in older MATLAB version.
- ➢ MATLAB has huge built-in library of functions
- ➢ MATLAB provides tool to develop GUI based applications.
- ➢ MATLAB is platform independent.
- ➢ MATLAB fundamental data type is array
- ➢ In MTLAB more than fifty such toolboxes available.
- ➢ MATLAB was one of the first commercial package of linear algebra.

AutoCAD

MODIFYING TOOLS-

Command	Function
Offset	The offset command in AutoCAD is used to create parallel lines, concentric circles, new line, Polyline and parallel curves. 
Array	The array is the command used to draw multiple copies of an object in a particular pattern or order. We can also manage the distance between the objects in the array.  Rectangular Array  Path Array  Polar Arrary
Fillet	The fillet command can be used to add round corners to the sharp eddges of the drawing.  Without Fillet  With Fillet
Explode	The EXPLODE Command in AutoCAD comes in handy when you wish to disassemble a component into its sub-components.  Before expolde  After explode
Scale	Alters or Scales the size of existing objects. 
Leader	Draws a line or series of lines with an arrow head called leader, to point to an object notate it. 

Editing Commands Shortcut-

Command	Shortcut	Command	Shortcut
Erase	E	Extend	Ex
Circle	C	Trim	Tr
Mirror	MI	Break	Br
Offset	O	Chamfer	Cha
Array	Ar	Fillet	F
Rotate	Ro	Explode	X
Move	M	Layer	LA
Scale	Sc	Unit	UN
Stretch	S	Zoom	Z
Lengthen	Len	Regen	Re

DRAWING COMMANDS

Command	Shortcut	Command	Shortcut
Line	L	Spline	Spl
Mutliline	ml	Ellipse	El
Polyline	pl	Text	T
Polygon	Pol	Dimension	Dim
Rectangle	Rec	Insert	I
Dount	do		

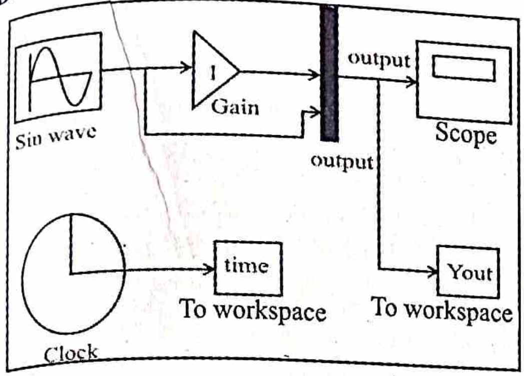
Functions-

Key Combination	Description
F1	Online Help
F3	Object Osnap ON/OFF
F6	Coords ON/OFF
F7	GRID ON/OFF
F8	Ortho ON/OFF
F9	GRID Snap ON/OFF
F11	Object snap Tracking ON/OFF
CTRL+A	Select all
CTRL+C	Copy CLIP
CTRL+G	Turn GRID ON/OFF
CRTL+N	Create a New drawing
CTRL+O	OPEN an existing drawing
CTRL+P	PLOT a dialog box
CTRL+S	Save a drawing
CTRL+X	Cut to clipboard
CTRL+Z	UNDO
CTRL+Y	Redo

3D Modeling and View

Simulink

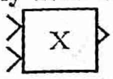
Basic Simulink model

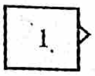


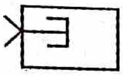
Block libraries of Simulink

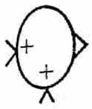
- **Commonly used blocks-**

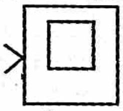
Gain

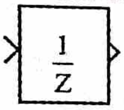

Product


Constant


Terminator

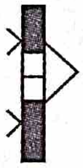

Sum

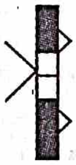

Scope


Unit Delay

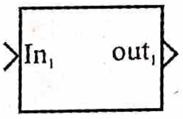
Mux

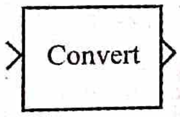
Demux

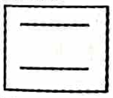

Bus creater

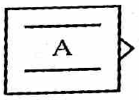

Bus Selector

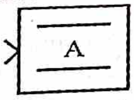
Vector concatenate


Sub system


Data Type Conversion


Data store memory


Data store Read


Data Store write

- **Simulink model six distinct blocks-**

Block Name	Specification	Location
Sin Wave	Amplitude = 2v Frequency= 1rad/s	Sources
Scope	Time range = 10s	Sinks
Gain	Gain=5	Math operations
Mux	Two Inputs	Signal Routing
Clock	None	Sources
To workspace	Save Format = Array	Sinks

❑ Model Creation-

- **Step to create a working model with Simulink:**

a. Collect all the necessary blocks from the Library Browser.

b. Modify the blocks so that they correspond to the blocks of the desired model.

c. Connect the desirable blocks with lines to form the complete system and set the overall Simulator parameters.

d. Simulate the complete system to verify (check) that it works.

☞ Remember point

- Graphical block diagramming tool with customizable set of block libraries.
- Simulink developed by math works, is a data flow graphical programming language tool for modeling simulating and analyzing multi-dynamic systems.
- It allows you to incorporate MATLAB algorithms into models as well as export the simulation results into MATLAB for further analysis
- Simulink design verifier allows you to indentify design errors and to generate test case scenarios for model checking.
- Capable of systematic verification and validation of models through modeling style checking, requirements traceability and model coverage analysis.
- **Sources-** Used to generate various signals. Source blocks have output but no inputs.

Example- Constant, a sin wave, a step, a Ramp, a pulse Generator, or a uniform random number to simulate noise, or the clock to create time index for plotting purposes.

- **Sinks-** Used to output or display signals. Sink block, have inputs but no outputs.

Example- Scope, To workspace, Floating scope, XY Graph, etc.

- **Discrete-** Discrete filter, Discrete zero pole, Discrete state-space, Discrete Transfer Fcn, unit Delay.
- **Signal Routing-** Switch, Mux, Demux, etc.
- **Math Operations-** SUM, Abs, Gain, Product, slider Gain, Sign etc.
- **Continuous signal-** Integrator, Transfer FCn, State-space, zero-pole, etc.

In Simulink Some other add-on products provided by MathWorks

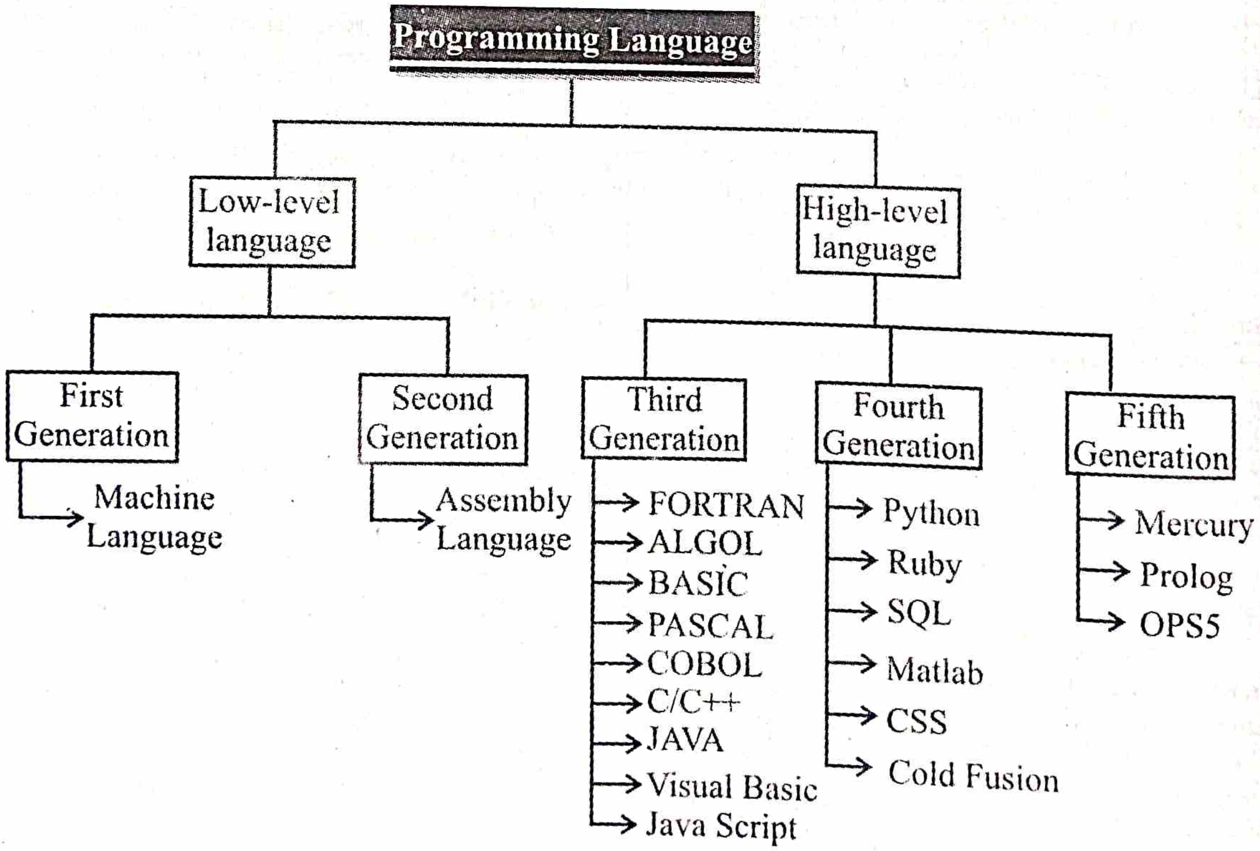
- **State flow** allows developing state machine and flow charts
- **Simulink coder-** allows the generation of C source code for real time implementation of systems automatically.
- **xPC-** Target together with x86-based real time systems provide an environment to simulate and test Simulink and state flow models in real-time on the physical system.
- Embedded coder supports specific embedded targets.
- **HDL Coder** allows to automatically generate synthesizable VHDL and verilog.
- **Sim Events-** provides a library of graphical building blocks for modeling queuing system.

PROGRAMMING LANGUAGE

☐ Evolution of programming languages

Period of employment	Programming language	Characteristics
1940s	Machine language	• Machine dependent • Faster execution • Difficult to use and understand • More prone to errors
1950s	Assembly language	• Machine dependent • Faster execution • More prone to errors • Relatively simple to use
1950-1970	FORTRAN, LISP, COBOL, ALGOL 60, BASIC, APL	• High-Level languages • Easy to develop and understand programs • Less prone to errors
1970-1990	C, C++, Forth, Prolog, Smalltalk, Ada, Perl, SQL	• Very high-level language • Easier to learn • Highly portable
1990s	Java, HTML, VB, PHP, XML, C#	• Internet-based languages • Object-oriented languages • More efficient • Reliable and robust

■ Generations of Programming languages


Programming Language
Low-level language
High-level language
First Generation
Machine Language
Second Generation
Assembly Language
Third Generation
FORTRAN
ALGOL
BASIC
PASCAL
COBOL
C/C++
JAVA
Visual Basic
Java Script
Fourth Generation
Python
Ruby
SQL
Matlab
CSS
Cold Fusion
Fifth Generation
Mercury
Prolog
OPS5

❑ Language processors: Assembler, Compiler and Interpreter

Parameters	Compiler	Interpreter	Assembler
Conversion	It converts the high defined programming language into machine language or binary code.	It also converts program developed code into machine language or binary code.	It converts programs written in the assembly language to the machine language or binary code.
Scanning	It scans the entire program before converting it into binary code.	It translate the program line by line to the equivalent machine code.	It converts the source code into the object code then convert it into the machine code.
Error Detection	Given the full error report after the whole scan.	Detects error line by line and stops scanning until the error in the previous line is solved.	It detects errors in the first phase, after fixation the second phase starts.
Code Generation	Intermediate code generation is done in the case of compiler.	There is no intermediate code generation.	There is an intermediate object code generation.
Execution Time	It takes less execution time comparing to an interpreter.	An interpreter takes more execution time than the compiler.	It takes more time than the compiler.
Examples	C, C#, Java, C++	Python, Perl, VB, Post script, LISP, etc.	GAS, GNU.

■ Algorithm, Pseudo code and Program

Algorithm	Pseudo code	Program
It is systematic logical approach, which is a well-defined, step-by-step procedure the allows a computer to solve a problem	It is a simpler version of a programming code in plain English which uses short phrases to write code for a program before it is implemented in a specific programming language.	It is exact code written for problem following all the rules of the programming language. A program is a set of instructions for the computer to follow.
Algorithms are generally written in a natural language or plain English language.	Pseudocode is written in a format that is similar to the structure of a high-level programming language.	Program on the other hand allows us to write a code in particular programming language
Algorithm of linear search- Step 1 - Start from the left most element of arr[] and one by one compare X with each element of arr[]. Step 2 - If X matches with an element, return the index. Step 3 - If X doesn't match with any of elements, return-1.	Pseudocode for linear search-	Program for Linear search.

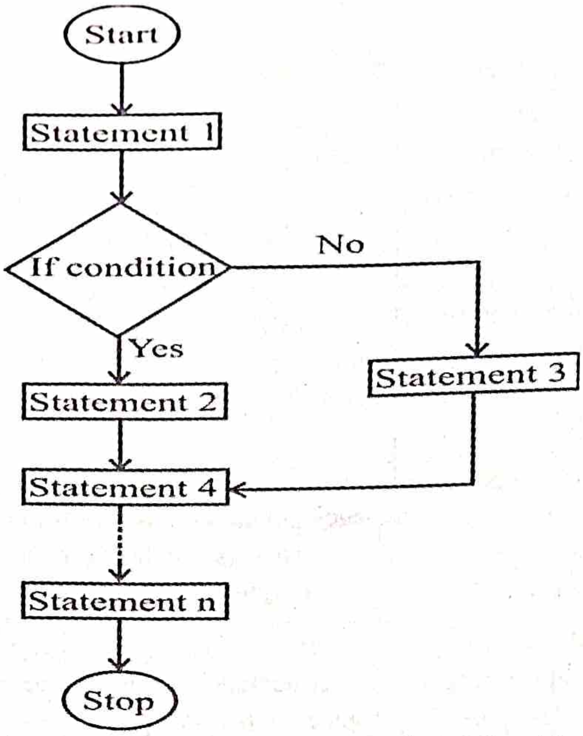
Pseudocode for linear search-

```
FUNCTION linear search (list,
search Term):
For index FROM O → length (list):
IF list [index] = search Term
THEN
RETURN index
END IF
ENDLOOP
RETURN – 1
END FUNCTION
```

Program for Linear search.

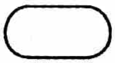
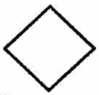
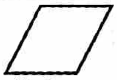
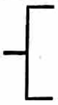
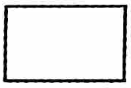
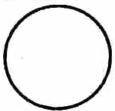
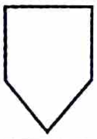
```
int search (int arr [], int n, intx)
{
  int i;
for (i = 0; i < n; i ++;)
if (arr [i] = = x)
return i;
return – 1 ;
}
```

❑ Flowchart



– **Flowchart** (Pictorial representation of a process) of statements in the If-Then-Else selection structure-

■ Symbols of Flowchart

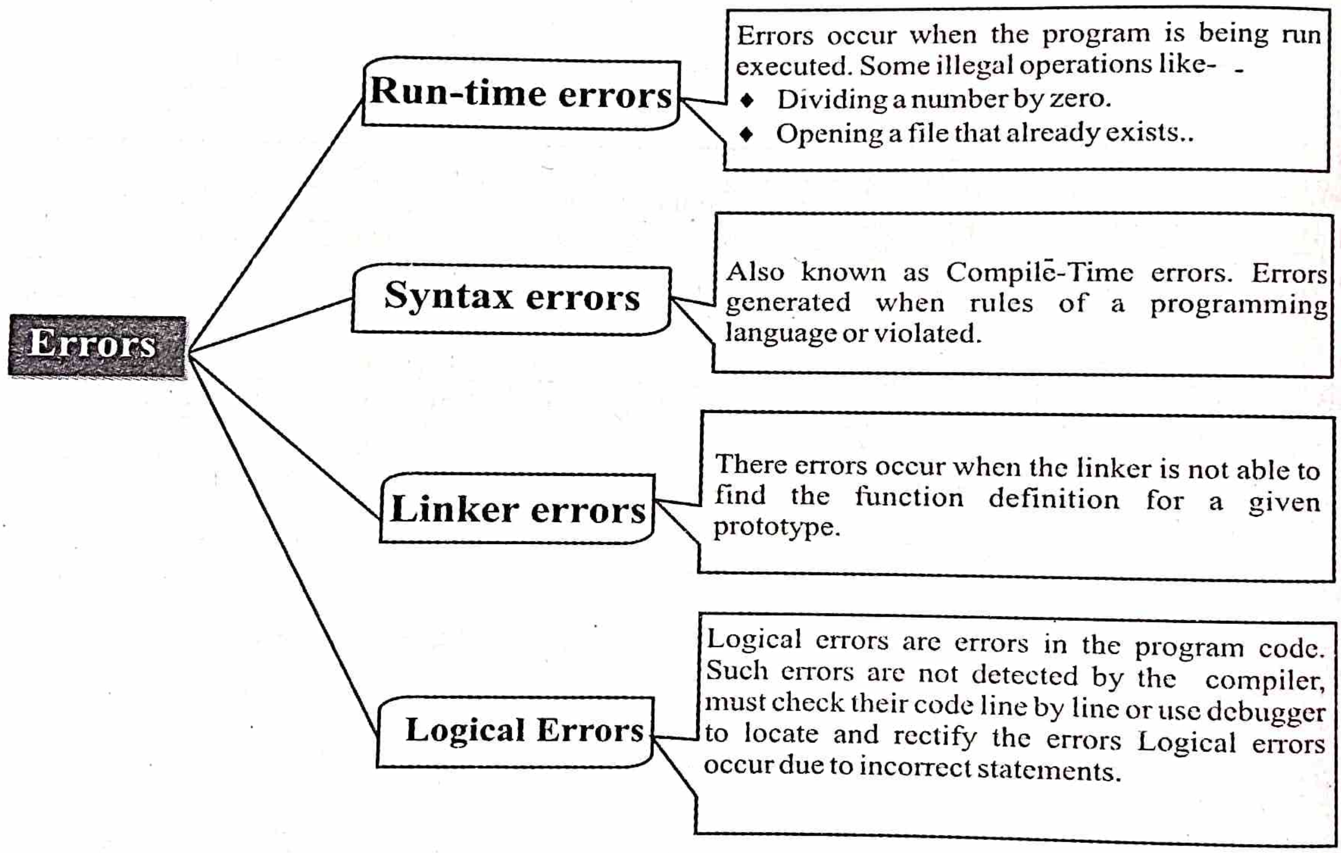
Symbols	Name	Function
→ (Arrow)	Flow line	Shows the process direction. Each flowline connects two blocks.
 (Oval)	Terminal (Start/Stop)	It is indicates the beginning or end of a flowchart.
 (Diamond)	Decision	Shows a step that decides the next step in a process. This is commonly a Yes/No or True/False question.
 (Parallelogram)	Input / Output	It is indicates the process of inputting or outputting external data.
	Comments	It is indicates additional information regarding a step in process.
 (Rectangle)	Process	Process symbol represents a step in a process
 (Circle)	On-page Connector	Pairs of on-page connector are used to replace long lines on a flowchart page.
	Off-page Connector	An off-page connector is used when the target is on another page.

■ Popular High-Level Language-

Languages	Release Date	Developer	Significant Characteristics
FORTRAN (FORmula TRANslation)	1957	John Backus	• It is easier to learn as compared to the other scientific high-level language. • It has a powerful built-in library containing some useful functions, which are helpful n performing complex mathematical computations. • It enables the programmers to create well-structured and well-documented programs.
LISP (LISt Processing)	1958	John McCarthy	• LIPS (List Processing) is easy to write and use. • It is most suitable for artificial intelligence (AI) applications • It is supports garbage collection and interactive computing.
COBOL (COmmon Business Oriented Language)	1959	COnference on DAta SYstem Languages (CODASYL) committee.	• It has several built-in functions to automate the various tasks in business domain. • It can handle and process a large amount of data at a time and in a very efficient manner. • It does not implement the concept of pointers, user-defined data types, and user-defined functions and hence is simple to use.
BASIC (Beginner's All-purpose Symbolic Instruction Code)	1964	John Kemeny and Thomas Kurty	• It is first interpreted language • It is easy to learn as it uses common English words • It is a general-purpose language.
PASCAL	1970	Niklaus Wirth	• It enables the programmers to develop well-structured and modular programs that are easy to maintain and modify. • The data in this language is stored and processed with the help of strong data structures. • The PASCAL compiler has strong type checking capability that prevents the occurrence of data type mismatch errors in a program.
C	1972	Dennis Ritchie and Brain Kernighan	• C is machine and operating system independent language. • It can be used to develop a variety of applications, hence, it is considered to be quite flexible. • It allows the programmer to define and use their own data types.
C++	1979	Bjarne Strous Trup	• It uses the concept of objects and classes for developing program • The code developed in this language can be reused in a very efficient and productive manner. • The number of instructions required to accomplish a particular task in C++ is relatively lesser as compared to some of the other high-level programming languages.
JAVA	1995	James Gosling	• It is a highly object-oriented and platform independent language. • The programs written in this language are compiled and interpreted in two different phases.

			• It assists the programmers in managing the memory automatically with a feature called garbage collection. • It also implements the concept of dynamic binding and threading in a better and efficient manner as compared to other object-oriented languages.
Python	1991	Guido Van Rossum	• It is an interpreted and object-oriented programming language. • The syntax and the semantics of this language are quite clear and concise. • It is a platform independent language.
C# (C-Sharp)	2000	Anders Hejlsberg (Microsoft)	• It is object-oriented visual programming and component-oriented language. • It is multimedia (audio, animation and video) supported. • It is suitable for web-based applications and language interoperability.

■ Errors occur in programming languages



Errors occur when the program is being run executed. Some illegal operations like-

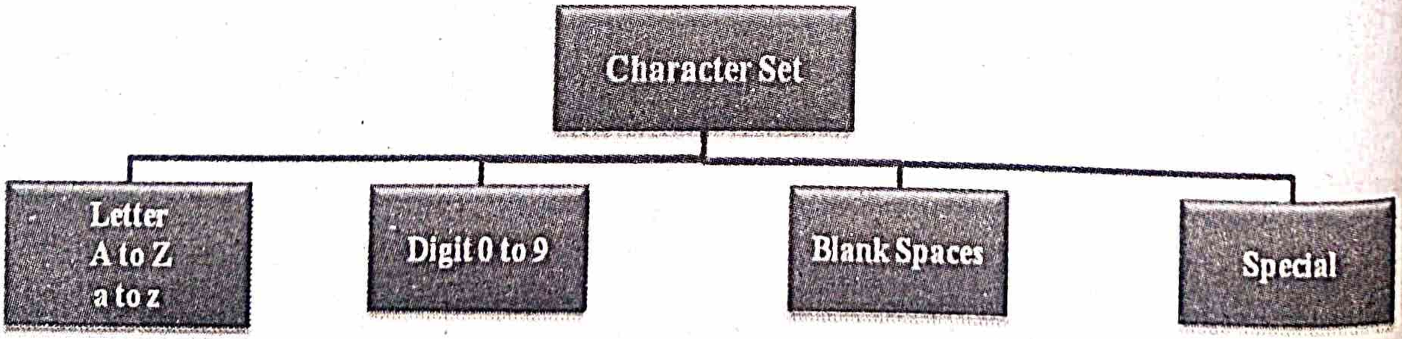
- ◆ Dividing a number by zero.
- ◆ Opening a file that already exists..

Also known as Compile-Time errors. Errors generated when rules of a programming language or violated.

There errors occur when the linker is not able to find the function definition for a given prototype.

Logical errors are errors in the program code. Such errors are not detected by the compiler, must check their code line by line or use debugger to locate and rectify the errors Logical errors occur due to incorrect statements.

■ Character set, keywords and Data types used in programming language.

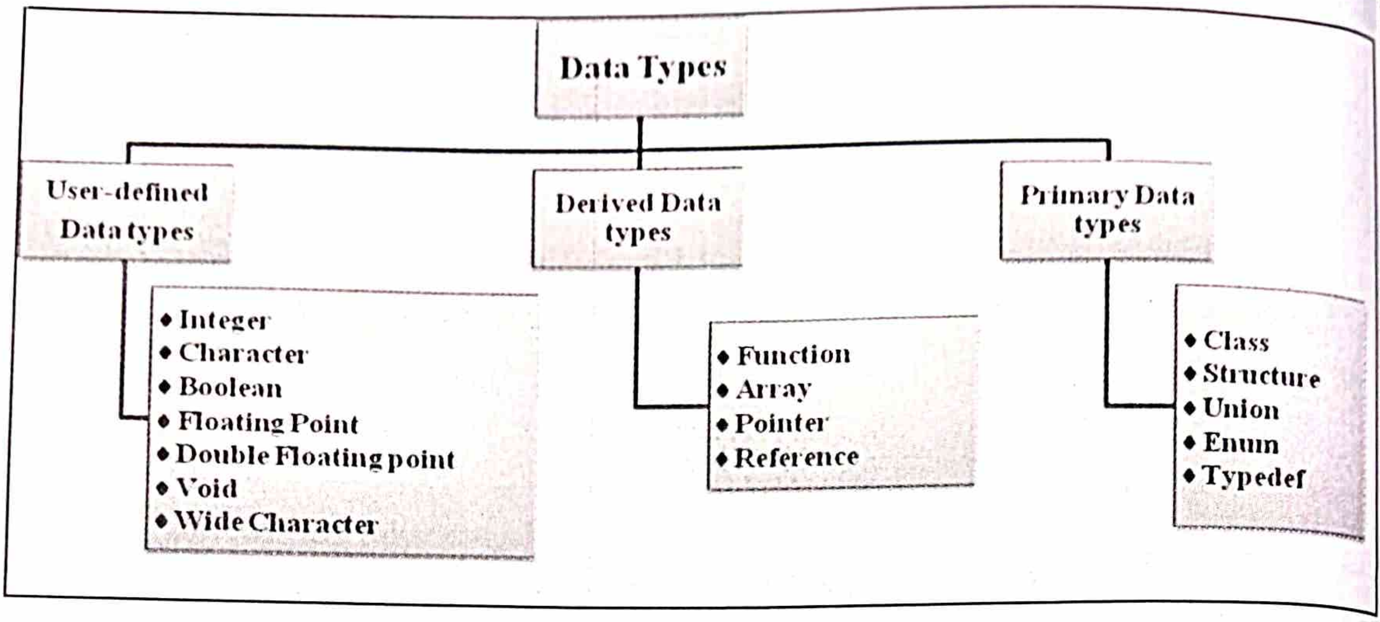


Special symbols

Special Symbol	Name	Special Symbol	Name
!	Exclamation sign	{	Left braces
#	Pound sign	}	Right braces
$	Dollar sign	[	Left bracket
%	Percentage sign	]	Right bracket
^	Caret	\	Backward slash
&	Ampersand	/	Forward slash
*	Asterisk	,	Comma Sigh
(	Left Parenthesis	.	Period
)	Right parenthesis	;	Semicolon
–	Underscore	:	Colon
-	Minus sign	‘	Apostrophe
+	Plus sign	“	Quotation marks
?	Question mark	~	Tilde

Keywords used in C

auto	else	long	Switch
break	Else if	Register	Then
Char	Extern	Return	Typedef
Const	Float	Short	Union
Continue	For	Signed	Unsigned
Default	Go to	Size of	Void
Do	If	Static	Volatile
Double	int	Struct	While


Data Types
User-defined Data types
Derived Data types
Primary Data types
• Integer
• Character
• Boolean
• Floating Point
• Double Floating point
• Void
• Wide Character
• Function
• Array
• Pointer
• Reference
• Class
• Structure
• Union
• Enum
• Typedef

Data type	**Size (in bytes)**	**Range of values**
Char	1	-128 to 127
Signed char	1	-128 to 127
Unsigned char	1	0 to 255
Short	2	-32,768 to 32,767
Singned short	2	-32,768 to 32,767
Unsingned short	2	0 to 65, 535
int	2	-32768 to 32767
Singned int	2	-32768 to 32767
Unsingned int	2	0 to 65535
Short int	2	-32768 to 32767
Singned short int	2	-32768 to 32767
Unsingned short int	2	0 to 65535
Long int	4	-2,147,483,648 to 2,147,483,647
Singned long int	4	-2,147,483,648 to 2,147,483,647
Unsingned long int	4	0 to 4,294,967,295
Float	4	3.4 E – 38 to 3.4 E + 38
Double	8	1.7 E – 308 to 1.7 E + 308
Long double	10	3.4 E – 4932 to 1.1 E + 4932

Operators

Category	Operator Symbol	Description
Arithmetic Operators	**Unary Operators**	
	++	Increments a given number
	– –	Decrements a given number
	Size of	Determines the size of a variable in bytes
	(type)	Converts the data type of a variable
	Binary Operators	
	+	Performs addition operation
	–	Performs subtraction operation
	*	Performs multiplication operation
	/	Performs division operation
	%	Calculates the remainder after division
Relational Operators	<	Less than
	>	Greater than
	< =	Less than equal to
	> =	Greater than equal to
	= =	Is equal to
	! =	Not equal to
Logical Operators	&&	Performs logical AND operation
	||	Performs logical OR operation
	!	Performs logical NOT operation
Assignment Operators	=	Assigns the right hand side value of the expression to the left hand side value of the expression
	+ =	Adds the variables present on either side of the expression. $\boxed{a+=b \Rightarrow a=a+b}$
	– =	Subtracts the variables present on either side of the expression. $\boxed{a-=b \Rightarrow a=a-b}$

	* =	Multiplies the variables present on either side of the expression. $\boxed{a * = b \Rightarrow a = a * b}$
	/ =	Divides the variables present on either side of the expression. $\boxed{a / = b \Rightarrow a = a / b}$
	% =	Performs the modulus operation on the variables present on either side of the expression. $\boxed{a \% = b \Rightarrow a = a \% b}$
Bit-manipulation Operators	&	Performs AND operation on the bits of the operands.
	| |	Performs OR operation on the bits of the operands
	~	Performs NOT operation on the bits of the operands.
	^	Performs XOR operation on the bits o f the operands.
	>>	Shifts data bits to the right.
	<<	Shifts data bits to the left.

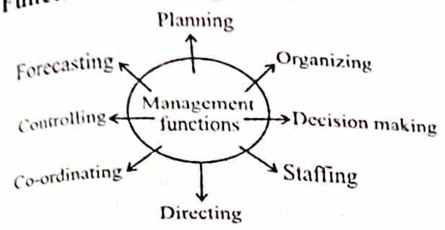
■ Precedence of Operators

Types of operator	**Operators**	**Associativity**
Unary Operators	+, –, !, ~, + +, –, type, size of	Right to left
Arithmetic operators	*, /, %, +, –	Left to right
Bit-manipulation operators	< <, > >	Left to right
Relational operators	>, <, >=, <=, = =, !, =	Left to right
Logical operators	&&, | |	Left to right
Conditional operators	?, :	Left to right
Assignment operators	=, + =, – =, * =, / =, % =	Right to left

IMED, IMRE AND ENERGY CONSERVATION

IMED

- **Function of Management-**


Planning
Forecasting
Organizing
Controlling
Management functions
Decision making
Co-ordinating
Staffing
Directing

- **Economic Order Quantity (Q)**

$$\boxed{Q=\sqrt{\frac{2U.P.}{C}}} \quad \text{or} \quad Q=\sqrt{\frac{2U.P.}{C_1\times C_2}}$$

Where,
U = Total quantity used per year
P = Procurement cost for a single order
C = Annual Carrying cost per unit item

- **Profit-volume ratio (P/V) Ratio-** The profit volume (P/V) Ratio is the measurement of the rate of change of profit due to change in sales.

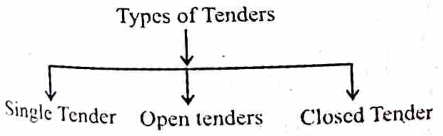
$$\boxed{P/V\,\text{Ratio}=\frac{\text{Sales}-\text{Variable cost}}{\text{Sales}}\times 100}$$

- Contribution = Sales – Variable cost
- $$\boxed{P/V\,\text{Ratio}=\frac{\text{Profit}}{\text{Margin of safety}}\times 100}$$
- $$\boxed{P/V\,\text{Ratio}=\frac{\text{Marginal contribution}}{\text{Sales}}\times 100}$$
- **Break Even Point**

$$\boxed{\text{Break Even point}=\frac{\text{Fixed cost}}{\text{selling price-Variable per unit}}\times 100}$$

- **Break Even sales volume**

$$\boxed{\text{B.E.S.V.}=\frac{\text{Fixed cost}}{\text{Contribution Per unit}}}$$

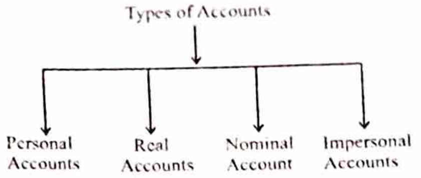

Types of Tenders
Single Tender
Open tenders
Closed Tender

➢ Single Tender is sought from one of the Trusted suppliers.

➢ Single Tender means an invitation to tender sent to a single party.

➢ Open tender is also known as press tender

➢ Closed tender is also known as limited tender.


Types of Accounts
Personal Accounts
Real Accounts
Nominal Account
Impersonal Accounts

➢ Personal account are the financial records of any person who can be a debtor or a creditor.

➢ Real Accounts are the records which are related to materials like cash, goods, machines, building etc.

➢ Nominal Accounts are records of expenses, receipts losses, such as salary, wages, business expenses, internet commission.

➢ These real and nominal accounts are collectively called impersonal accounts.

- **Various providing assistance to small-scale Industries**

➢ District Industry centers (DIC$_S$)

➢ Commercial Banks

➢ State Financial corporations (SFC$_S$)

➢ Small Industries service Institutes (SISI$_S$)

➢ Small Industries Development Bank of India (SIDBI)

➢ National Bank for Agriculture and Rural Development (NABARD)

➢ National Small Industries corporation (NSIC)

➢ National research Development corporation (NRDC)

➢ Technical consultancy organizations commission, (TCOC)

➢ Khadi and Village Industries Commission (KVIC)

➢ Science and Technology Entrepreur park (STEP)

➢ Micro, small and medium Enterprises

➢ Technology-Business Incubators

➢ National Institute for Entrepreneurship and small Business Development (NIESBUD)

➢ Hardicon Ltd.

- **According to the TRIPS, types of intellectual property rights-**

1. Copyright and Related Right
2. Trademark
3. Patent
4. Industrial Design
5. Design of Integrated circuits
6. Geographical Indication
7. Protection of undisclosed Information

- **P.D.C.A. CYCLE**

Plan	Do
Establish the objective and plan for an assessment of environmental management	Education, communication Management of Document Administrative control and emergency reaction
Act	**Check**
Correction, Prevention measure and study on management	Monitoring Compliance assessment and internal judge Analysing Results

- **EXAMPLES OF ASSET**

CURRENT ASSET	FIXED ASSETS
Cash	Property, plant, Equipment
Accounts receivable	Real Estate Investment
Inventory	Patent, Copyright
Short-term investments	Loan (more than one financial year)
Prepaid Expenses	Biological Assets
Loan	Good will
Petty cash	Investment mode the using equity method

- **Elements of Total Quality management (TQM)-**

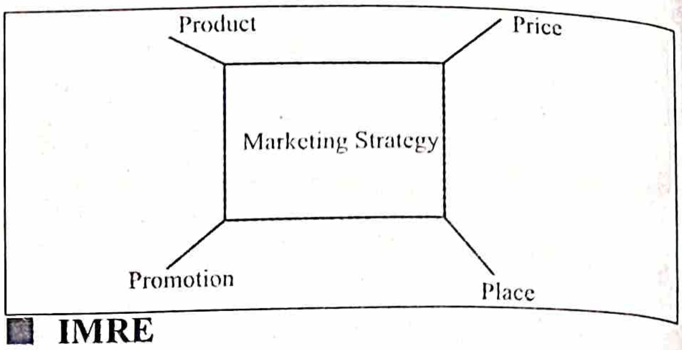
➢ Customer's Satisfaction ➢ Do it Right First Time
➢ Continuous Improvement ➢ Employee Involvement
➢ Empowering the Staff ➢ Benchmarking
➢ Feed Back.

Remember Point-

➢ LOB is a line of Business.
➢ The equation 'Assets=Liabilities + Equity is related to balance sheet.'
➢ Industrial Finance corporation of India (IFCI) is known as first development bank of India.
➢ ISO 9000 standard is embedded in a quality management system within an organisation.
➢ Idea stage is first stage of product planning and development process.
➢ Commercialization is the last stage of product planning and development process.
➢ In Manifest conflict organizational conflict is open aggression seen.
➢ Entrepreneur are market risk taker.
➢ An entrepreneur who owns more than one business at a time is called A portfolio entrepreneur.
➢ Technological is said to be an external risk factor for an entrepreneur.
➢ The work done at right time is called just in time.
➢ The first and foremost function of management is planning.
➢ Innovation can be best defined as The successful exploitation of new ideas.
➢ Number of orders issued for

$$\text{Purchase} = \frac{\text{Total quantity}}{\text{E.O.Q.}}$$

➢ Total procurement cost (a) = Number of orders for purchase × cost of a purchase
➢ Marketing strategy



IMRE

☐ Remember Point-

- Predictive maintenance is also known as 'Condition based maintenance' strategy.
- Routine maintenance is also called as cyclical maintenance.
- Reactive maintenance is also known as Breakdown maintenance.
- Preventive maintenance also known as planned maintenance.
- Replacement of worn out part can done during breakdown maintenance.
- Special inspection test conducted for overhead line after heavy rains, cyclone.
- Breakdown maintenance also known as corrective maintenance.
- Ringing test of insulator for cracking.
- The maintenance performance on regular basis to reduce the likelihood of failure is preventive maintenance.
- Wet flashover test of Insulator is also known as rain test.
- The maintenance performed on equipment that has broken down and is unusable is breakdown maintenance.

Energy Conservation

☐ Boiler efficiency

- **Direct Method-**

$$\text{Boiler efficiency} = \frac{\text{Heat output}}{\text{Heat input}} \times 100$$

$$= \frac{Q \times (h_g - h_f)}{q \times GCV} \times 100$$

Q = Quantity of steam generated per hour in (kg/hr)
q = Quantity of fuel used per hour (kg/hr)
h_g =Enthalpy of saturated heat in kcal/kg
h_f = Enthalpy of feed water in kcal/kg
GCV = Gross Calorific value of the true. (kCal/kg)

- **Blow down-**

$$\text{Blow down} = \frac{\text{Feed water TDS} \times \%\ \text{Makeup}}{\text{Maximum permissible TDS in boiler water}}$$

- **Energy Efficiency Ratio-**

The energy efficiency ratio (EER)

$$= \frac{\text{Output cooling energy in BTU}}{\text{input electrical energy in Wh}}$$

Energy saving tips in refrigerator

- Protect your fridge from heat sources
- Tidy up your condenser coils
- Replace the Rubber seal on the Door.
- Cool off your leftovers
- Keep the door closed
- Take Advantage of in-door water and ICE
- Reduce your frost Accumulation switch
- Initiate the power saving switch
- Check the temperature Inside
- Organize and Remove Clutter your Refrigerator.

Energy units and conversions

1Watt	= 1 Joule/s
1kW	= 1000W
1kWh	= 3.6×10^6 J=3.6 million Joules
1 Mega-Joule	= 278 Wh
1 BTU	= 252 Cal
1BTU	= 1055 Joule
1BTU/h	= 0.29071W
1 kilo caloric/hour	= 1.163W
1 CHU	= 453.5 Cal
1 CHU	= 1899 J
1 CHU	= 1.8 BTU
1 CHU/hr	=0.527W

Tons of refrigeration (TR)

$$TR = \frac{Q\times C_P\times(T_i - T_O)}{3024}$$

Where,

Q = Mass flow rate of coolant in kg/hr

C_P = Coolant specific heat kcal/kg.°C

T_i = inlet, temp or coolant to evaporator in °C

T_0 = outlet, temp of coolant from evaporator in °C

- **Coefficient of performance (Carnot)-**

$$COP_{carnot} = \frac{T_e}{(T_c - T_e)}$$

Where, T_e= evaporator

T_c= condenser temperature

$$COP = \frac{\text{Cooling effect (kW)}}{\text{Power input to compressor (kW)}}$$

- **In case air conditioning units-**

$$TR = \frac{Q\times\rho\times(h_{in} - h_{out})}{3024}$$

Where, Q = The air flow in m^3/h

f = Density of air kg/m^3

h_{in}= Enthalpy of inlet kCal/kg

h_{out}= Enthalpy of outlet air kCal/kg

- **An indicative TR load-**

Small office cabins = $0.1 TR/m^2$

Medium size = $0.06 TR/m^2$

Large multistoried = $0.04 TR/m^2$

Compressor Performance-

- **Isothermal efficiency**

$$= \frac{\text{Isothermal power}}{\text{Actual measured input power}}$$

$$\text{Isothermal power (kW)} = P_1\times Q_1\times \log_e r/36.7$$

r_1 = Pressure ratio, $\frac{P_2}{P_1}$

P_1 = Absolute in take pressure kg/cm^2

P_2 = Absolute deliver pressure, kg/cm^2

Q_1= Free air delivered m^3/hr

- **Volumetric efficiency**

$$= \frac{\text{Free air delivered }(m^3/min)}{\text{compressor displacement }(m^3/min)}$$

$$\text{Compressor displacement} = \frac{\pi}{4}\times D^2\times L\times S\times\chi\times n$$

Where, D= Cylinder bore, metre

L= Cylinder stroke, metre

S = Compressor speed rpm

χ = 1 for single acting and 2 for double acting cylinder

n = number of cylinders

Energy Conversion values used for working out annual Energy consumption in terms of MOE

- 1kWh = 860 kCal
- 1 kg charcoal = 6900 kCal
- 1kg Furnace oil = 10050 kCal
- 1kg HSD = 11,840 kcal
- 1 kg Petrol = 11,200 kCal
- 1 kg Kerosene = 11,110 kCal
- 1 kg LPG = 12,500 kCal
- $1m^3$ Natural Gas = 8,000–10,500 kCal
- 1 kg of oil Equivalent = 10, 000 kCal
- 1 Metric Tone of oil Equivalent = 10×10^6 kCal

Energy saving tips in computer-

- By Energy Efficient products
- Use Build in power saving Features
- Turn Down the Brightness
- Turn off the monitor Instead of using a screen saver
- Disable Devices that are Not needed
- Turn off the computer
- Share Hardware where Appropriate.

Energy saving in lighting-

- Reduce the wattage
- Avoid Multiple Fittings
- Use Multiple switches
- Install Dimers
- Use Lamps
- Install motion Detectors
- Go Solar
- Keep Lights clean
- Turn the Light off

Benchmark parameters:

a. Gross production related-

- kWh/kg yarn produced (Textile unit)
- kWh/MT clinker or cement produced (Cement plant)
- kWh/MT, k Cal/kg, paper produced (Paper plant) kcal/kWh Power produced (Heat rate of a power plant)
- Million kcal/MT urea or Ammonia (Fertilizer plant)
- kWh/MT of liquid metal output (in a foundry)

b. Equipment/utility related-

- kW/ton of refrigeration (On Air Condoning Plant)
- kWh/NM^3 of Compressed air generated
- kWh/litre in a diesel Power plant
- While such benchmarks are referred to, related crucial process parameters need mentioning for meaningful comparison among peers for instance in the above case-
- For a cement plant-type of cement, blaine number (fineness) i.e. Portland and process used (Wet/dry) are to reported alongside kWh/MT.
- For a textile unit average count, type of yarn i.e. polyester /cotton is to be reported along side kWh/ m^2
- For a paper plant-paper type, raw material (recycling extent), GSM quality is some important factor to be reported along with kWh/MT, kcal/kg.
- For an Air Conditions plant- Chilled water temperature level and refrigeration load (TR) are crucial for comparison kW/TR

Star Labelled Appliances-

- **Mandatory Appliances-**
  - Frost Refrigerators (Frost-Free)
  - Tubular Florescent Lamp
  - Distribution Transformer
  - Room Air conditioners (Cassette, Floor standing Tower, Ceiling, Corner AC)
  - Direct cool Refrigerator
  - Electric Geysers
  - Color TV
  - Room Air Conditioners (Invert Type)
  - LED lamps

Products under voluntary Labelling-

- Induction Motors
- Pump sets
- Ceiling fans
- LPG stoves
- Washing machine
- Computer (Notebook/Laptops)
- Ballast (Electronic/Magnetic)
- Office equipments (Printer, Copier, Scanner)
- Diesel Generator
- Chillers
- Microwave ovens
- Deep Freezers
- Light Commercial Air Conditioners (LCAC)

Energy conservation in furnaces

- Complete Combustion with minimum excess air
- Correct heat distribution
- Operating at desired temperature
- Reducing heat losses from furnace opening
- Minimum refractory losses
- Use of ceramic castings
- Make sure the filter is clean
- Use a programmable Thermostat
- Curtains are a Great way to save ENERGY
- Use ceiling fans
- Optimum capacity utilization
- Keep a Good Humidity levels
- Decorative Insulation
- Make sure your Garage Door is seeded

BENEFITS OF ENERGY SAVING-

- Significantly Reduce your utility Bills
- Earn a Great return on your investment
- Enhance your Quality life
- Increase your property value
- Protect the environment
- Energy Savings Tips Help you Easily cut costs
- Earn Incremental Return on ENERGY efficiency
- Insulate yourself from rising Electrics prices.

GENERAL ENERGY SAVING TIPS-

- Automate your house
- Use eco-friendly
- Have your house inspected
- Incorporate renewable energy sources
- Plan your energy use
- Unplug unused appliances
- Make your own energy-saving devices
- Avoid using electrical appliances if you can

ENERGY SAVING TIPS IN BLOWERS

- Use low-slip or no-slip belts
- Check belt tension regularly
- Eliminate variable pitch pulley
- Use variable speed drives for large variable blower loads.
- Minimize blower inlet and outlet obstructions.
- Clean screens and filters regularity
- Use smooth, well-rounded air inlet ducts that could lead to reduced electricity bill.
- Eliminate duct - work leaks
- turn blowers off when they are not needed
- Use energy-efficient motors for continuous or near continuous operation.

ENERGY SAVING TIPS IN WASHING MACHINES-

- Wash your clothes in cool water as often as possible
- Pre-soak stains
- Wait for a full load
- Run your machine on the shortest cycle
- Reduce the weekly loads
- Switch off the power at the wall
- Use Eco or speed perfect
- Use proper detergent
- Avoid dryers
- Use Different washing mode
- Switch to solar
- By Energy Efficient Machine

Do's and Don't of boiler operation

Don't

- Operate a boiler which is not constructed the American Society of Mechanical Engineers (A.S.M.E.) Code.
- Ever leave the boiler unattended for long periods of time.
- Operate a boiler without on adequate source of combustion air

- Operate a boiler without a valid certificate of inspection
- Permit unqualified personal to operate a boiler
- Ever bypass the pressure controls, low water cutout, or any other limit switch or control.
- Ever restrict the design function of any safety value, such as by reducing or plugging the outlet, painting, or removing it.

Do-

- Respect the boiler it can be dangerous.
- Have the vessel inspected internally annually as required by state law
- Test safety controls and devices on a periodic basis (as recommended by CSD1).
- Ensure boiler operators are adequately trained to assure safe and efficient operation
- Allow only authorized ("R" stamp or Proper ASME symbol holder) repair firms to make welded repairs.

❑ Energy saving tips in Cooking-

- Be Smart with your cooking
- Be Good to your fridge
- Smart Washing and Drying
- Fix Dripping Taps
- Doing the Dishes
- Clean the oven Door
- Don't over-fill the kettle
- Buy Energy Efficient Appliances
- Use the microwave
- Don't Leave Appliances on standby

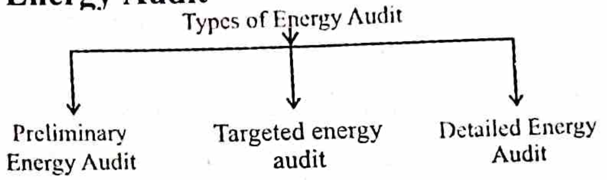
❑ ENERGY SAVING TIPS IN COLOUR TELEVISION-

- Watch TV on your Laptop or Desktop Computer.
- Get the family Together to watch TV.
- Tape your prime-Time favorites for later viewing.
- Turn down the volume.
- Turn Down the screen Lighting.

❑ ENERGY SAVING TIPS IN WATER PUMPS-

- Operate pumping near best efficiency point.
- Modify pumping to minimize throttling.
- Adapt to wide load variation with the variable speed drive or sequenced control of smaller units.
- Repair seals and packing to minimize water waste.
- Increase fluid temperature differentials to reduce pumping rates.
- User booster pumps for small loads requiring higher pressures.
- Select the right pump based on the usage.
- Choose the right pump size.
- Implement the right control valves.
- Make use of variable speed drives.

■ Energy Audit



❑ **Preliminary Energy Audit**-The Scope of preliminary energy Audit is to-

- ➢ Estimate the Scope for energy savings
- ➢ Arresting leaks (Steam, Compressed air)
- ➢ Controlling excess air by adjusting fan damper.
- ➢ Shutting equipment when not needed.
- ➢ Modifying process of reduce steam demand
- ➢ Replacement with appropriate lamp and luminaries.
- ➢ Converting from direct to Indirect steam heated equipment and recovery of condensate.
- ➢ Setup a baseline or reference line for energy consumption
- ➢ Identify the most likely and easiest areas for attention.
- ➢ Identify the most immediate (especially no/low cost) improvements/savings.

❑ Plant Survey or Mini Energy Audits-

- Targeted energy audits are mostly based upon the outcome of the preliminary audit results.
- They provide data and detailed analysis on specified target projects.
- As an example, an organization may target its lighting or boiler system or compressed air system with a view to bring about savings.
- Targeted audits therefore involve detailed surveys of the target subjects/with analysis of the energy flows and associated with those targets.

❑ Detailed Energy Audit-

Detailed Energy Audit evaluates all systems and equipment which consume energy and the audit comprises a detailed on energy savings and costs.

❑ Detailed Energy Audit carried out in 3 phases-

- The pre-audit phase
- The Audit phase
- The post-Audit phase

• Methodology for Conducting Detailed Energy Audit

Step No.	Plan of Action	Purpose/Results
	Phase I Pre- Audit Phase	
Step 1	• Plan and Organise • Walk through Audit • Informal Interview with Energy Manager, Production/Plant Manager	• Establish/organize a Energy audit team • Organize Instruments & time frame • Macro data collection (suitable to type of industry) • Familiarization with process/plant activities • First hand observation & Assessment of current level of operation and practices
Step 2	• Introductory Meeting with all divisional heads and persons concerned with energy management (1-2hrs)	• To built up cooperation • Orientation, awareness creation • Issue questionnaire tailored for each department

	Phase II-Audit Phase	
Step 3	• Primary data gathering, process Flow Diagram and Energy Utility Diagram	• Historic data collection and analysis for setting up Baseline energy consumption • All service utilities system diagram (e.g. single line power distribution diagram, water, and compressed air and steam distribution). • Prepare process flow charts • Design, operating data and schedule of operation • Annual Energy Bill and energy consumption pattern (refer manual, logbook, name plate etc.)
Step 4	• Conduct survey and monitoring	• Measurements: Motor survey, Insulation, Lighting survey etc. with portable instruments for operating data. Confirm and compare operating data with design data.
Step 5	• Conduct of detailed trials/tests for selected major energy equipment	• Trials/Tests - 24 hours power monitoring (MD, PF, kWH etc.). - Load variation trends in pumps, fan compressors etc. - Boiler Efficiency trials for (4-8 hours). - Furnace Efficiency trials. - Equipments performance test etc.
Step 6	• Analysis of energy use	• Energy and Material balance • Energy loss/waste analysis
Step 7	• Identification and development of Energy Conservation (ENCON) opportunities	• Conceive, develop and refine Ideas. • Review ideas suggested in previous energy audit report if any. • Use brainstorming and value analysis techniques. • Contact vendors for new/efficient technology
Step 8	• Cost benefit analysis	• Assess technical feasibility, economic viability and prioritization of ENCON options for implementation. • Select the most promising projects. • Priorities by low, medium, long term measures.
Step 9	• Reporting and Presentation the Top Management	• Documentation, draft Report Presentation to the top Management.
	Phase III-Audit Phase	
Step 10	• Implementation and Follow-up	Implementation of ENCON recommendation measures and Monitor the performance. • Action plan, schedule for implementation. • Monitoring and periodic review.

ENERGY AUDIT INSTRUMENTS-

Energy Audit Instruments	**Measure**
Fyrite	amount of gas percentage
Manometer with Pitot Tube	Pressures in air ducts carrying exhaust flue gases (boiler furnaces)
Combustion gas Analyzer	CO_2, CO, NO_x, SO_x etc.
Fuel efficiency Monitor	Measures oxygen and temperature of the flue gas
Contact thermometer	Flue gas, hot air hot water temperatures
Thermography	thermal radiation from hot and cold object.

- **Energy Conservation Building Code (ECBC) on 27th may, 2007**

ECBC sets minimum energy standards for commercial buildings having a connected load of 100 kW or 120 kVA. While the central government has power under the EC act 2001, the state governments have the flexibility to modify the code to suit local or regional needs and modify them.